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CONTENTS.

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VOLUME 7.

PHYLOGENY OF THE ECHINI,
WITH A REVISION OF PALAEOZOIC SPECIES.

BY ROBERT TRACY JACKSON.

WITH SEVENTY-SIX PLATES.

BOSTON:
PRINTED FOR THE SOCIETY
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3.

TO THE MEMORY OF THE LATE
ALEXANDER AGASSIZ,
TO WHOM THE SOCIETY MADE ITS FIRST AWARD
OF THE WALKER GRAND PRIZE
IN RECOGNITION OF HIS 'REVISION OF THE ECHINI,'

AND OF

ALPHEUS HYATT,
LATE CURATOR OF THE SOCIETY,
MY BELOVED MASTER AND FRIEND, WHOSE
PRINCIPLES OF RESEARCH ARE THE
KEYNOTE OF THIS MEMOIR.

TABLE OF CONTENTS.

PREFACE	Page.
INTRODUCTION	9
TERMINOLOGY	15
	25

PART I.

COMPARATIVE MORPHOLOGY OF ECHINI	31
FORM OF THE TEST	31
ORIENTATION	32
THE PENTAMEROUS SYSTEM AND VARIATION	35
STRUCTURE OF THE SKELETON AND GROWTH	51
THE AMBULACRUM OF THE CORONA	53
THE INTERAMBULACRUM	62
CHARACTERS OF BASICORONAL PLATES	69
IMBRICATION OF CORONAL PLATES	73
SPINES	77
THE PERISTOME	79
OCULAR AND GENITAL PLATES	86
SPECIAL CHARACTERS OF GENITAL PLATES	165
THE PERIPROCT	173
THE ARISTOTLE'S LANTERN AND PERIGNATHIC GIRDLE	177

PART II.

SYSTEMATIC CLASSIFICATION OF ECHINI	199
---	-----

PART III.

PALAEOZOIC ECHINI	235
GEOLOGICAL DISTRIBUTION	235
SYSTEMATIC DESCRIPTIONS	238

Order BOTHRIOCIDAROIDA Jackson	238	<i>A. triplex</i> White	274
Family BOTHRIOCIDARIDAE Klein	238	<i>A. triserialis</i> (M'Coy)	275
<i>Bothriocidaris</i> Eichwald	238	<i>A. triserrata</i> Meek	275
<i>B. archaica</i> sp. nov.	239	<i>A. rankini</i> Young	276
<i>B. pahlani</i> Schmidt	242	<i>A. prisca</i> (Münster)	276
<i>B. globulus</i> Eichwald. Genotype	243	<i>A. werkei</i> Tornquist	276
Order CIDAROIDA Duncan	244	<i>A. urii</i> (Fleming). Genotype	276
Family CIDARIDAE Gray	245	<i>A. halliana</i> (Geinitz)	279
<i>Miocidaris</i> Döderlein	245	<i>A. mucsteriana</i> (Koninek)	280
<i>M. keyserlingi</i> (Geinitz)	245	<i>A. forbesiana</i> (Koninek)	280
<i>M. canoni</i> sp. nov.	247	<i>A. spinoclavata</i> Worthen and Miller	281
Order ECHINOCYSTOIDA nom. nov.	250	<i>A. sp. b.</i> Girty	281
Family PALAEODISCIDAE Gregory	250	<i>A. clavata</i> (Eichwald)	282
<i>Palaeodiscus</i> Salter	250	Lepidocidaris Meek and Worthen	282
<i>P. ferox</i> Salter. Genotype	250	<i>L. squamosa</i> Meek and Worthen. Genotype	282
Family ECHINOCYSTIDAE Gregory	252	Family LEPIDOCENTRIDAE Lovén	284
<i>Echinocystites</i> Wyville Thomson	252	<i>Koninckocidaris</i> Dollo and Buisseret	284
<i>E. pomum</i> Wyville Thomson. Genotype	252	<i>K. coltau</i> Dollo and Buisseret. Genotype	285
Order PERISCHOECHINOIDA M'Coy	253	<i>K. silurica</i> sp. nov.	285
Family ARCHAEOCIDARIDAE M'Coy	254	Lepidocentrus Müller	286
<i>Eocidaris</i> Desor	254	<i>L. rhenanus</i> (Beyrich)	288
<i>E. laevispina</i> (Sandberger). Genotype	255	<i>L. drydenensis</i> (Vanuxem)	288
<i>Archaeocidaris</i> M'Coy	256	<i>L. mülleri</i> Schultze	289
<i>A. wortheni</i> Hall	259	<i>L. whitfieldi</i> sp. nov.	290
<i>A. legrandensis</i> Miller and Gurley	260	<i>L. eifelianus</i> Müller. Genotype	291
<i>A. longispina</i> Newberry	261	Tornquistellus Berg	291
<i>A. glabrispina</i> (Phillips)	261	<i>T. gracilis</i> (Tornquist). Genotype	291
<i>A. nerei</i> (Münster)	262	Hyattechinus gen. nov.	291
<i>A. rossica</i> (Buch)	263	<i>H. rarispinus</i> (Hall)	292
<i>A. agassizi</i> Hall	266	<i>H. pentagonus</i> sp. nov.	295
<i>A. illinoisensis</i> Worthen and Miller	266	<i>H. beecheri</i> sp. nov. Genotype	297
<i>A. coloradensis</i> nom. nov.	267	Pholidechinus gen. nov.	299
<i>A. keokuk</i> Hall	267	<i>P. brauni</i> sp. nov. Genotype	299
<i>A. gracilis</i> Newberry	267	Family PALAEECHINIDAE M'Coy	302
<i>A. aculeata</i> Shumard and Swallow	268	<i>Palaeechinus</i> M'Coy	304
<i>A. shumardana</i> Hall	268	<i>P. quadriserialis</i> Wright	305
<i>A. edgarcensis</i> Worthen and Miller	269	<i>P. ellipticus</i> M'Coy. Genotype	307
<i>A. newberryi</i> Hambach	269	<i>P. elegans</i> M'Coy	308
<i>A. trudifer</i> White	269	<i>P. (?) minor</i> sp. nov.	310
<i>A. norwoodi</i> Hall	270	Maccoya Pomel	311
<i>A. paradoxa</i> (Eichwald)	270	<i>M. burlingtonensis</i> (Meek and Worthen)	312
<i>A. mucronata</i> Meek and Worthen	271	<i>M. intermedia</i> (Keeping)	314
<i>A. dininnii</i> White	271	<i>M. phillipsiae</i> (Forbes)	316
<i>A. cratis</i> White	272	<i>M. sphaerica</i> (M'Coy)	317
<i>A. acanthifera</i> Trautschold	272	<i>M. gigas</i> (M'Coy). Genotype	321
<i>A. pizzulana</i> Gortani	272	<i>M. gracilis</i> (Meek and Worthen)	323
<i>A. megastyla</i> Shumard and Swallow	273	Lovenechinus gen. nov.	324
<i>A. biangulata</i> Shumard and Swallow	273	<i>L. lacazei</i> (Julien)	326
<i>A. ornata</i> (Eichwald)	274		
<i>A. ourayensis</i> Girty	274		

<i>L. mutatus</i> (Keyes)	335	<i>L. iowensis</i> sp. nov.	397
<i>L. nobilis</i> (Meek and Worthen)	335	<i>L. tessellatus</i> sp. nov.	397
<i>L. missouriensis</i> (Jackson). Genotype	337	<i>L. imbricatus</i> Hull. Genotype	399
<i>L. onglicus</i> sp. nov.	346	Perischodomus M'Coy	401
<i>L. septies</i> sp. nov.	348	<i>P. biserialis</i> M'Coy. Genotype	401
Oligoporus Meek and Worthen	350	<i>P. illinoisensis</i> Worthen and Miller	406
<i>O. blairi</i> Miller and Gurley	351	Perischocidaris Neumayr	407
<i>O. coreyi</i> Meek and Worthen	353	<i>P. harteiana</i> (Bailey). Genotype	408
<i>O. sulcotus</i> Miller and Gurley	354	Proterocidaris Koninck	409
<i>O. holli</i> sp. nov.	355	<i>P. giganteus</i> Koninck. Genotype	410
<i>O. danae</i> (Meek and Worthen). Genotype	356	Lepidesthes Meek and Worthen	412
Melonechinus Meek and Worthen	359	<i>L. wortheni</i> Jackson	416
<i>M. dispar</i> (Fischer von Waldheim)	365	<i>L. laevis</i> Trautschold	418
<i>M. parvus</i> (Hambach)	365	<i>L. formosa</i> Miller	418
<i>M. springeri</i> sp. nov.	366	<i>L. devonicens</i> Whidborne	420
<i>M. crassus</i> (Hambach)	367	<i>L. spectabilis</i> (Worthen and Miller)	421
<i>M. indianensis</i> (Miller and Gurley)	369	<i>L. coreyi</i> Meek and Worthen. Genotype	423
<i>M. stewartii</i> (Safford)	371	<i>L. carinata</i> sp. nov.	424
<i>M. septenarius</i> (Jackson)	373	<i>L. colletti</i> White	425
<i>M. obovatus</i> sp. nov.	373	<i>L. extremis</i> sp. nov.	430
<i>M. liratus</i> sp. nov.	374	<i>L. caledonica</i> sp. nov.	432
<i>M. multiporus</i> (Norwood and Owen). Genotype	375	Pholidocidaris Meek and Worthen	432
<i>M. keepingi</i> sp. nov.	384	<i>P. irregularis</i> (Meek and Worthen). Genotype	434
<i>M. ethridgii</i> (Keeping)	385	<i>P. sp.</i>	440
<i>M. vanderbilti</i> sp. nov.	388	<i>P. tenuis</i> Tornquist	440
<i>M. giganteus</i> (Jackson)	389	<i>P. ocuaria</i> (Whidborne)	441
Family LEPIDESTHIDAE Jackson	393	<i>P. gaudryi</i> (Julien)	442
Lepidechinus Hall	394	Meekechinus gen. nov.	442
<i>L. irregularis</i> (Keeping)	396	<i>M. elegans</i> sp. nov. Genotype	443
<hr/>			
INCERTAE SEDIS	446	<i>E. striatus</i> Eichwald	450
<i>Archocidaris konincki</i> Desor	446	<i>E. sp.</i> Austin	450
<i>A. ladina</i> Stache	446	<i>Melonitiden</i> Tornquist	450
<i>A. scotica</i> Young	447	<i>Oligoporus</i> (?) <i>minutus</i> Beede	450
<i>A. selwyni</i> R. Etheridge, Jr.	447	<i>Palacchinus</i> (?) <i>konigii</i> M'Coy	450
<i>A. siri</i> Barrois	447	<i>Palaeochinus regnyi</i> nom. nov.	451
<i>A. trautscholdi</i> Tornquist	448	<i>Palaeochinus robineti</i> Julien	452
<i>A. sp.</i> Meek and Hayden	448	<i>Paleochinus</i> sp. Tornquist	452
<i>A. sp.</i> Meek and Hayden	448	<i>Palaeocidaris exilis</i> Eichwald	453
<i>A. sp.</i> Stache	448	<i>Palaeodiscus gothicus</i> Wyville Thomson	453
<i>A. (?) sp.</i> Worthen and Miller	448	<i>Palaeospatangus skiptoni</i> Harte	453
<i>A. sp.</i> R. Etheridge, Jr.	448	<i>Perischodomus magnus</i> Tornquist	453
<i>A. sp.</i> Julien	449	Protoechinus T. Austin	453
<i>A. sp.</i> Julien	449	<i>P. anceps</i> T. Austin. Genotype	454
<i>A. sp.</i> Julien	449	<i>Rhoechinus</i> sp. Duncan	454
<i>Cidarites tennesseae</i> Troost	449	<i>Rhoechinus</i> (?) sp. Tornquist	454
<i>Echinocrinus anceps</i> T. and T. Austin	449		
<i>E. spinosus</i> T. and T. Austin	449		

INCERTAE SEDIS (*continued*).⁶

Xenocidaris Schultze	454
<i>X. clavigera</i> Schultze. Genotype	455

<i>X. conifera</i> Schlüter	455
<i>X. cylindrica</i> Schultze	456

NOMINA NUDA

<i>Archacocidaris tirolensis</i> Stache	456
<i>Echinocrinus cidariformis</i> (?) T. and T. Austin	456
<i>Echinocrinus pomum</i> T. and T. Austin	456
Heterocidaris Hall	456
<i>Heterocidaris kcokek</i> Hall	456
<i>Heterocidaris laevispina</i> Hall	456

456	
<i>Lepidocentrus desori</i> Dollo and Buisseret	457
<i>Lepidocentrus duponti</i> Dollo and Buisseret	457
<i>Lepidocentrus gaudryi</i> Dollo and Buisseret	457
<i>Melonites youngi</i> Young	457
<i>Palaechinus agassizi</i> Dollo and Buisseret	457
<i>Palaechinus carpenteri</i> Dollo and Buisseret	458
<i>Palaechinus loveni</i> Dollo and Buisseret	458

PALAEOZOIC FORMS INCORRECTLY REFERRED TO ECHINI

Discocystis Gregory	458
<i>D. kaskaskiensis</i> (Hall)	458
<i>D. optatus</i> (Worthen and Miller)	458
<i>D. sampsoni</i> (Miller)	485

Myriastiches Sollas	458
<i>M. gigas</i> Sollas	458
<i>Palacchinus</i> sp. Mitchell	458
Spatangopsis Torell	458
<i>S. costata</i> Torell	458

BIBLIOGRAPHY	459
INDEX	475
ERRATA AND ADDENDA	491

PREFACE.

IN 1896, I published with Dr. (now Professor) T. A. Jaggar, Jr., a detailed study of *Melonechinus multiporus* and at the same time, independently, a general study of Palaeozoic Echini. These papers, which were published together in the Bulletin of the Geological Society of America, were the first attempt to make a comprehensive study of this interesting group of fossil animals.

During a year recently spent in Europe, opportunity offered to study most of the European species of Palaeozoic Echini and in many cases the types. In this country similar opportunities have been enjoyed with American species. The great liberality and kindness of all to whom I applied for permission to study material is later acknowledged in detail, but I cannot refrain from saying here that the freedom and liberality with which the choicest and rarest material was placed in my hands and every facility offered for study at home and abroad, was one of the pleasantest experiences of my life.

The present memoir is naturally divided into three parts: first, a study of the development and comparative morphology of Echini, based on the young, adult, fossil, and living types; second, a proposed systematic classification of Echini based on the preceding studies; third, a revision of Palaeozoic Echini comprising the systematic description of all known forms.

The late Professor Alpheus Hyatt originated most important and novel methods of study in Palaeontology. It is both an obligation and a privilege to say that during many years, when closely associated with him as student and assistant, he impressed upon me the important principles of stages in development, senescence, acceleration, and parallelism. During my first sea-urchin studies I had the privilege of his ever ready sympathy and personal help. I have tried to carry out this work on his lines and as he would have done it, so far as in me lay. The Hyatt principles are the pith and center of the work, and I take pleasure in feeling that his views worked out largely on the Mollusca are supported and strengthened by their application to another group of animals.

In revising a group, it is most important to see the types or original specimens on which species have been based. Omitting Incertae Sedis, the types have been studied of 69 of the 119 species of Palaeozoic Echini described in this memoir. Specimens of 96 of the species have been studied. These include almost all of the important forms.

The genera and species of Palaeozoic Echini have for the most part been described in the publications of geological surveys as parts of the fauna of a horizon or locality, or as descriptions of a limited number of species in the proceedings of learned societies.

Of those who have published on Palaeozoic Echini, the most important are as follows. M'Coy did pioneer work; in 1844 he published several species of *Palaeochinus*, the first known, also species of *Archaeocidaris*, and later, *Perischodomus*. James Hall described several new species of *Archaeocidaris*, also *Lepidechinus*. Meek and Worthen, or Meek independently in a few cases, did most accurate and painstaking work, describing many genera and species with a care and faithfulness that have rarely been equalled by investigators of these ancient and difficult fossils. Sir Wyville Thomson described the remarkable *Echinocystites*. Baily published observations on *Palaeochinus* and described *Perischocidaris harteiana*. Schmidt made important studies of *Bothriocidaris*, describing a new species. Keeping described new species and published good figures of old species. Duncan made studies of the ambulacrum in species of the *Palaeochinidae*. C. A. White described a number of new species of *Archaeocidaris* and a *Lepidesthes*. Keyes described a new species of *Oligoporus*, published a number of new figures, and gave a revision of the American species. Jaekel published a careful study of a species of *Bothriocidaris*. Jackson and Jaggar published a detailed study of *Melonechinus multiporus*, and Jackson a general study of Palaeozoic Echini, described a few new species, and made an attempt at a natural classification. Julien described new species and figured others from the Carboniferous of France; his material was evidently not very good as shown by the photographic illustrations. Tornquist made a careful study of German species with most excellent figures; he described a number of new species and genera and gave a classification. Miss Klem published a revision of Palaeozoic Echini with a synopsis of known species. Her bibliography and synonymies are very full and most helpful, but unfortunately there are many errors in the text, so that statements need verification. Fraipont published an interesting series of species from the Carboniferous of Belgium.

Besides the above, new species or genera of Palaeozoic Echini or observations on specimens have been published by many authors. Aldrovandus, in 1618, published the first Palaeozoic echinoid that has been discovered in the literature. He figured at this early date a specimen of *Bothriocidaris globulus* under the caption, "*Echinus lapis spoliatus a spinis*." It is extraordinary that this especially rare type should have been so early discovered. De Koninck, Münster, L. Agassiz, Norwood and Owen, Fischer von Waldheim, Forbes, Geinitz, King, Roemer, J. Müller, and Sandberger published species and genera with more or less full descriptions of the same. Desor published some new forms and gave a revision of the then known Palaeozoic species. Young, Wright, Shumard, Schultze, and Safford published a few types, some of much importance. Lovén in his "*Études*" gave a revision of the then known species, but apparently without observations on specimens. A. Agassiz in the "*Revision*" (1872-'74, p. 644-650) gives a general discussion of Palaeozoic Echini and in several other monographs has published observations on the group and some discussions of the observations of others. Stache, Miller, and Schlüter published new species. Zittel in his text-book introduced new

generic names and higher divisions of the group. Pomel gave a revision of the genera and published a number of new ones. This part of his work was apparently based wholly on the observations of others, to whom he gives neither credit nor reference. Waagen, and Miller and Gurley published new species. Duncan revised the genera in his revision of the genera of the class. Sollas, Gregory, Whidborne, Dollo and Buisseret, Girty, Bather, and Spencer published new species or observations on older species. In numerous text-books, figures and more or less full descriptions are of course given, wholly or mainly from the observations of others. The important monographs of A. Agassiz, Lovén, and Mortensen have been constantly in hand for comparative studies of recent types. The late lamented Alexander Agassiz stands unique in the history of echinology, for his work on the group extended over a period of nearly fifty years, during which time he published numerous extensive monographs besides many smaller papers.

The attempt has been made to give full credit to the above authors for their observations. While I have not always been able to agree with the observations or conclusions of others, it is to be remembered that these fossils have a complex structure and are often very imperfectly preserved, so that they are exceptionally difficult to study. Also, I have had the privilege of a fuller opportunity than probably any one before to study a large range of Palaeozoic species. Those who are most familiar with the group can best appreciate the difficulty of avoiding errors, as I hope may be remembered in my own case. Barring possible oversights, the systematic part of this paper includes every published species, practically all of which are figured. A figure is given of all recognized species excepting *Archaeocidaris rankini*, *A. prisca*, and *Koninckocidaris cotteau* of which no specimen was available and no figure has been published. Also excepting *Pholidocidaris gaudryi* of which the published photographic figures are too indistinct to be safely copied. The location in museums of types and rare species is given as an aid to investigators.

For their kindness and liberality in allowing me freest access to material in collections and for every facility in the use of the same, as well as other kindnesses, I would return grateful thanks to the following curators and private collectors. My friend, Dr. F. A. Bather, of the British Museum, to whom I am under special obligations, most kindly helped me by correspondence and the loan of rare specimens, as well as by access to the rich material in the British Museum. He also had the great kindness to borrow, study, and send me drawings and notes on the specimen of *Lovenechinus lacazei* described from the York Museum. During a visit at the British Museum I enjoyed the privileges of the rich library facilities there available. Dr. F. L. Kitchin and Mr. H. A. Allen, of the Geological Museum in Jermyn Street, London, helped in a similar way, and most kindly had photographs taken of some of their important specimens as here reproduced. Professor Henry Woods, of Cambridge, England, and Professor John Joly, of Trinity College, Dublin, gave access to their choice material. Dr. R. F.

Scharff, of the Science and Arts Museum, Dublin, gave me access to invaluable material, had casts and photographs of M'Coy's types made, and most generously brought over to this country for study one of their most valuable specimens. Dr. Otto Jackel, recently of Berlin, kindly gave me the opportunity to study his most precious specimen of *Bothriocidaris*, which I feel is the backbone of this work. Professor A. Rothpletz and Dr. F. Broili gave me every opportunity to study the rich collections of the Munich Museum. At Geneva, Dr. Bedot, Director of the Musée d'Histoire Naturelle, and Dr. Jules Favre, of the same institution, kindly gave me access to their rich collection of Recent and Mesozoic Echini, including the very valuable material of the late M. de Loriol. Professor G. Steinmann and Professor G. Boehn, of Freiburg i. Br., and Professor A. Tornquist, of Strassburg, placed much fine material at my disposal.

In this country, for opportunities to study fossil Echini, I am under deep obligations to many curators of museums and to private collectors. Mr. Samuel Henshaw, Curator of the Museum of Comparative Zoölogy, kindly gave me free access to the rich collections in that institution. From Professor Charles Schuchert, of Yale University Museum, besides other specimens, was borrowed the superb material of *Hyattechinus beecheri* and *rarispinus* collected in Warren, Pennsylvania, mostly by the late Professor C. E. Beecher. I am under similar obligations to the late Professor R. P. Whitfield, of the American Museum of Natural History; Dr. C. D. Walcott and Dr. R. S. Bassler, of the United States National Museum; Dr. George H. Girty, of the United States Geological Survey; Professor Stuart Weller, of the University of Chicago; Professor John M. Clarke, of the New York State Museum; Professor William B. Clark, of Johns Hopkins University; Professor J. W. Beede, of Indiana University, who sent me the remarkable new type, *Meekechinus elegans* and other material; Dr. A. G. Ruthven and Professor E. C. Case, of the University of Michigan; Professor R. S. Breed, of Alleghany College, Meadville, Pennsylvania; Professor L. C. Glenn, of Vanderbilt University; Professor A. W. Grabau, of Columbia University; and Mr. C. W. Johnson, Curator of the Boston Society of Natural History.

Of private collectors, Mr. Frank Springer generously loaned me his whole collection of about 125 Palaeozoic Echini, including types and other material recently purchased from Professor G. Hambach, of St. Louis. Mr. Frederick Braun, of Brooklyn, lent very choice material from his private collection; and Mr. E. Kirk, now of the United States Geological Survey, lent several specimens. Mr. J. E. Hyde, of Columbia University, loaned the remarkable new *Lepidesthes extremis*. To all these gentlemen I would render warmest appreciation for their generosity. The actual specimens loaned or used will be referred to as from the institution or collection to which they belong under consideration of the species.

For the opportunity to study the great collection of Recent Echini in the Museum of Comparative Zoölogy, I am indebted to the Curator, Mr. Samuel Henshaw, and to Dr. Hubert Lyman Clark, who is in charge of that department. For similar opportunities in the United

States National Museum I am indebted to Mr. Austin H. Clark and Miss Mary J. Rathbun. Professor Verrill kindly gave me the opportunity to study the Recent Echini in Yale University Museum. The authorities at Ward's Natural Science Establishment at Rochester liberally allowed me to study their large trade collection. For opportunities to study Recent material in their charge, I am indebted also to Mr. Roy Miner, of the American Museum of Natural History; Dr. F. A. Lucas, lately of the Brooklyn Institute of Arts and Sciences; Dr. A. S. Pearse, of the University of Michigan; and Professor E. S. Morse, of the Peabody Museum at Salem. Professor Morse also kindly gave me opportunity to study many Japanese Echini that he collected in that country. Several gentlemen have most kindly supplied me with fine series of specimens; they are: Mr. A. P. Romine, of Bellingham, Washington; Dr. W. K. Fisher, of Stanford University; Professor W. E. Ritter, of the University of California; Professor E. L. Mark, of Harvard University; Dr. H. C. Chadwick, of the Port Erin Biological Station; Dr. F. D. Lambert, of Tufts College; Dr. Thomas Barbour, of Cambridge, Massachusetts; Mr. Dwight Blaney and Mr. Owen Bryant, of Boston. Dr. Theodor Mortensen kindly loaned me valuable material and helped me by correspondence.

In addition to material studied in various institutions, my work has been based on my own collection of some 40,000 Recent and Mesozoic Echini. These I recently gave to the Museum of Comparative Zoölogy. My Palaeozoic Echini, accumulated during many years and including 100 specimens, are now also in the collection of the same Museum.

I would express my warm obligations to my friend, Mr. Samuel Henshaw, Curator of the Museum of Comparative Zoölogy, for the use of a room and for the use of the great library facilities there afforded.

I would express my deep appreciation of the laborious painstaking care and skill with which Mr. J. Henry Blake made the larger part of the drawings for the plates and text-figures. It is very difficult to get an artist who can draw a sea-urchin correctly, and without Mr. Blake's skill and patience I should have been badly handicapped. Any sea-urchin is difficult to draw accurately, but in the Palaeozoic, one has to contend with the difficulties of imperfections, often the fusion or indistinctness of sutures; the fossils are frequently external or internal molds or siliceous replacements, and these conditions add much to the difficulties of critical study and correct interpretation. The drawings were all made under my eye, and are as faithful to the originals as it was possible to make them. No restorations were permitted, except as indicated by dotted lines. Of the text-figures, Mr. Blake drew figures 1 to 239 and 245 to 253, while figure 244 is the work of Mr. J. H. Emerton; figures 240 to 243 were done by Mr. A. H. Searle, and figures 254 to 256 by Mr. William M. Barrows. I would also express obligations to Mr. F. A. Saunderson, of Boston, for the remarkable set of photographs of Echini which are reproduced as heliotypes. Some of the drawings and photographs were made by other artists in Europe or this country, as mentioned in the description of plates. The illustra-

tions in the plates are arranged as nearly as practicable in systematic sequence following the classification here presented.

I am under great obligations to my friend, Dr. Hubert Lyman Clark, for his help in verifying references, and help with my manuscript and other matters during my absence from home. Miss H. I. Cowdery rendered valuable service as a typewriter by her careful painstaking copying of the manuscript for the printer.

The requisite research work and the preparation of this memoir have taken my close attention in available time for some seven years. That it has taken so long has been a source of regret for more than one reason, but careful work cannot be done in a hurry. I adopt the title "Phylogeny of the Echini" for this memoir, because the phylogenetic relations expressed by stages in development and by variation are considered throughout the work. As I have shown previously in my "Phylogeny of the Pelecypoda" (1890), and also in studies of Echini (1896), and of Plants (1899), I believe that by following the Hyatt methods of a comparative study of young, adult, fossil, and living forms we can arrive at a series of facts which justify us in accepting them as expressing an approximation to the real genetic relationships of the forms under consideration. The genealogical relations of the Echini, as understood from the results of my studies, are shown in tabular form on p. 209.

INTRODUCTION.

The principles made use of and the methods of work employed in studying Echini are here treated before starting into the detailed considerations. The one essential principle that has been applied consistently throughout is the principle of stages in development and the constant comparison of these stages with the characters of more or less closely associated types. This principle applied conjointly to fossil and living forms was urged by Professor Louis Agassiz, and was the center of a large part of Professor Hyatt's work. An attempt has been made to bear in mind the characters of the young, adult, and old age, and to compare these with the young or with the adult of simpler or more specialized types, both living and fossil. As far as material permitted, the entirety of the organism has been taken into account. If Echini have taught me anything, they have impressed upon me that classification should be based on the sum of the characters and not on single characters.

Herbert Spencer pointed out the distinction that growth is mere increase in size without the addition of differential characters; development is the addition of differential characters. Development proceeds rapidly during the early growth of an organism, but in later life we may get extensive growth without any development. In Palaeozoic Echini, development, that is, the addition of new characters, is often long continued, so that new characters, especially additional columns of interambulacral plates, may be taken on up to or even dorsal to the mid-zone. Then in the dorsal region we come into the zones of localized stages in development, where the young, last added plates are progressively taking on their full characters as they are pushed ventrally by the intercalation of still younger plates on their dorsal border, between them and the apical disc. Dorsally, we also often find senescent stages or characters of regressive development, especially marked by the dropping out of columns of interambulacral plates, as in *Melonechinus indianensis* (Plate 53, fig. 1).

In the Palaeozoic Echini, as elsewhere, specimens of a species vary in size, and doubtless this usually means age, but really young specimens are almost unknown. The only very young one seen is *Lovenechinus missouriensis* (Plate 39, fig. 1; compare with adult, Plate 39, fig. 5). In the absence of the young, youthful stages are gathered from the characters of the plates at the ventral area of the corona, which, as shown in my earlier paper, is an area that preserves the early stages of development in a remarkable degree. Except when destroyed by resorption, this area in a perfect specimen represents the first interambulacral plates built in any corona, and the first ambulacral as well, unless they have passed on to the buccal membrane. While these ventral plates have increased in size since early youth, their presence, number, angles,

and mutual relations show developmental stages which it is felt, from numerous and careful comparisons, can be trusted as stages in development. Stages in development are not limited to the ventral border, but are seen in many types appearing progressively up to or even dorsal to the mid-zone. This is especially seen in the development of the interambulacrum, where new columns come in often very late in the growth of the individual, as shown in numerous cases, for example, *Melonechinus multiporus* (Plate 57, fig. 1).

Localized stages in development is the principle that throughout the life of the individual, stages may be found in definite parts that are comparable to the condition in the young and to the adults of simpler types of the group. This principle was discovered in and applied to the young plates at the dorsal portion of the interambulacrum in Palaeozoic Echini in my paper, "Studies of Palaeochinoidea," published in 1896, p. 228. It was applied to Palaeozoic and Recent Echini in my paper (1899) on this principle as a new law in evolution published in the Memoirs of the Boston Society of Natural History, under the title, "Localized Stages in Development in Plants and Animals." In this memoir the principle of localized stages in development is applied to the interambulacrum, but especially to the ambulacrum, where it is found that primitive characters, seen in the nascent plates at the dorsal border of the area, are striking and most valuable for a comparison with the condition in the young and with simpler types in the group. This principle is shown well in the development of young ambulacral plates dorsally in *Centrechinus* (text-figs. 92, 94, pp. 106, 107) and is seen especially in the family Palaeochinidae (text-fig. 237, p. 231). This principle was found to have a broad application in various groups of organisms, as ophiurans, crinoids, corals, cephalopods, also plants; and it has been taken up by the late lamented Professors Hyatt and Beecher, by Grabau, Cushman, Ruedemann, Buckman, Hubert Lyman Clark, and Jeffrey, who found it a valuable aid in studying many different groups of animals and plants.

Senescence, which was made so much of by Professor Hyatt in his studies of cephalopods, is best shown in Palaeozoic Echini by the dropping out of columns of interambulacral plates at the dorsal or last built portion of the test. In the old individual of *Lovenechinus missouriensis* (Plate 42, fig. 6) columns 1 and 2 have in part dropped out dorsally, whereas in a younger specimen (Plate 41, fig. 2) they continue directly to the apical disc. *Melonechinus giganteus* (Plate 59, fig. 14) shows the dropping out of the eleventh or last added column at the dorsal border of the area. Dropping out of columns is shown graphically in the old-age *Melonechinus indianensis* (Plate 53, fig. 1) where columns 1 and 2 or even more drop out before reaching the apical disc. *Hyattechinus beecheri* (Plate 26) shows the dropping out of columns 1 and 2 toward the dorsal portion of the areas.

Progressive types are those which show in their development to maturity the addition of differential characters only, without the dropping out or disappearing of such characters, unless in senescence. A good case of a purely progressive type is *Palaeochinus quadriserialis* (Plate 30,

fig. 3), which progressively adds characters, but as far as known does not lose any of these additions. It may be said that in general most Palaeozoic Echini are progressive types.

Regressive types are those which, after attaining a degree of specialized characters, in later development, and before old age, lose some of these characters, so that what we call the adult, as gathered especially from the characters of the mid-zone, is simpler than its own young. An excellent case of this is *Lepidesthes wortheni* (Plate 67, fig. 8) which in the young has four columns of interambulacral plates, but the fourth column drops out early, and in later life it has three columns only. The sixth column represented by only a few plates in an area seems to mark *Lovenechinus missouriensis* (Plate 41, fig. 1) as a regressive type, at least in this character. To go outside of Palaeozoic Echini, Hemicidaris has compound ambulacral plates in the lower or youthful half of the test, and above this point has only simple plates, showing a complete reversion to Cidaris, a more primitive type of Echini. Such an extreme case may be compared to Lituities in cephalopods (Zittel, Handbuch der Palaeontologie, vol. 2, text-fig. 519), which, after an early coiled stage, takes on a straight stage directly comparable to the early straight forms of nautiloid cephalopods. Cases could be multiplied and some will be mentioned later, but here it is the object simply to point out examples that illustrate the principles made use of.

Acceleration of development, one of Professor Hyatt's most important principles, is abundantly shown in Palaeozoic Echini. Usually columns of interambulacral plates, after the first four columns, are added at considerable intervals, as in *Melonechinus multiporus* (Plate 57, fig. 1), but *M. giganteus* (Plate 59, fig. 14), which is a higher species in the series, adds the fifth, sixth, seventh, and eighth columns earlier than does *M. multiporus*, as shown in a detailed study in my earlier paper (1896, p. 179). *Hyattechinus beecheri* (Plate 26), a most specialized type, has a very accelerated development, and new columns of interambulacral plates are added so rapidly that the fourth to the tenth are added in succeeding rows, or even two columns may be added in a single row. The same character of acceleration is shown well in *Hyattechinus rarispinus* (Plate 23, fig. 1) and *H. pentagonus* (Plate 25, fig. 1). Acceleration is shown well in the ambulacrum in *Melonechinus* (text-fig. 237, p. 231), in which at the ventral border we find four plates in each ambulacrum, while the lower genera of its family have only two plates.

Parallelism is an important feature which was much studied by Professor Hyatt, and is of great value in studying Echini. Parallelism is the taking on of a similar character by independent lines, and is sometimes difficult to distinguish from real genetic connection. A case of parallelism is seen in the imbrication of plates of Echini. It has been thought that imbrication was a sufficiently important character to group together those forms that possessed it, but it is assumed independently in several distinct groups in the Palaeozoic, as well as in the post-Palaeozoic Echinothuriidae. In the family of the Palaeochiniidae (*Melonechinus*, etc.) ambulacral plates on the adradial suture are beveled over the adambulacra (Plate 45, fig. 5).

A similar beveling is seen in the petaloid area in some clypeastroids, Clypeaster, surely a parallelism only. Accessory pores in genital plates in modern Echini exist as an individual variation occasionally (Arbacia, text-figs. 197, 198, p. 171; Echinus and others). This apparently represents a parallelism rather than a genetic connection with the several pores characteristic of these plates in most Palaeozoic genera (Plate 56, fig. 6). Increase in the number of columns of interambulacral plates is taken on independently in many genera. The absence of resorption of the base of the corona, which permits of the retention of the single primordial interambulacral plate in each area, appears as a parallelism in many independent groups, as represented by Hyattechinus (Plate 26), Perischodomus (Plate 64, fig. 2), Pholidodiaris (Plate 73, fig. 6), Phormosoma, clypeastroids (text-figs. 43, 52, p. 80), and spatangoids (Plate 3, fig. 15).

Resorption is an important process to bear in mind; it occurs continuously in the growth of each individual plate, where there is a constant resorption within the plate concurrently with increase in external dimensions. Resorption of the base of the corona by the encroachment of the actinostome is a very important factor, as shown by Lovén (1892). In Palaeozoic types, as I showed in my earlier paper (1896), there is either no resorption (Hyattechinus, Plate 26), resorption of apparently one plate only (Palaeochinus, Plate 30, fig. 3), or resorption of several rows of plates (Archaeodiaris, Plate 9, figs. 6-8). Resorption may cut holes directly through the test, as shown by Mr. Agassiz (1872) in the development of the lunules in the recent *Mellita sexiesperforatus* (Leske). See text-figs. 22-31, p. 70.

Variation is an extremely important subject and is graphically shown in sea-urchins. Here we find the striking character of radial variation well developed, as seen especially in the corona and ocular and genital plates. One radius may be more or less accelerated, or may reach a greater or lesser degree of differential development than other radii in the same individual. This is especially marked in the variation of rate of development and number of columns of interambulacral plates attained in Palaeozoic Echini, and in the number of ocular plates reaching the periproct in Recent Echini. The range of radial variation in one individual may equal the range of variation of different individuals within the limits of the species. In *Melonechinus* typically there are four plates at the ventral border of the ambulacrum, but in one specimen of *Melonechinus multiporus* (Plate 57, fig. 3) it is seen that in area B there are two plates only. This is the normal character of the ventral border of *Oligoporus* (Plate 50, fig. 8) and *Lovenechinus* (Plate 42, fig. 1), the next lower genera of the family.

In order to appreciate variation it is of fundamental importance to be familiar with the characters of the associated species and genera of a case in hand, and also the developmental characters of the same. Variation may be fairly classified under five more or less distinct heads:

1. *Arrested variation*, in which the variant retains characters seen in its own young and

typical of the adults of more primitive allies, but characters which are usually eliminated in development. Arrested variants are shown abundantly in the consideration of ocular plates, when fewer plates may become insert than is characteristic of the species (*Tripneustes*, text-figs. 123-125, p. 124).

2. *Progressive variation*, in which the variant has characters not typical of the species, but which are further evolved on the direct line of differential development, and are seen typically in more evolved nearly allied species or genera. Such progressive variants are also shown abundantly in the consideration of ocular plates, where more plates become insert than is typical in the species (*Centreechinus*, text-figs. 93-95, p. 107 and 176, p. 153).

3. *Regressive variation*, in which the variant takes on characters of the adult of some simple and more primitive type of the group. Such characters are not necessarily a repetition of youthful characters but may go back to a remote ancestry. An arrested variant in a sense is one form of regressive variation, but a regressive variant includes much more than arrested variation. To distinguish them, an arrested variant is one that has developed to a certain point as usual, and then failed to take on the later added characters typical of the species, so that, although an adult, it has immature characters. A regressive variant is one that has attained full characters and then in later life has reverted to youthful or primitive characters as an individual variation, or it is a variant that from youth has primitive characters not normally seen in the development of the species. A modern horse with extra digits as in Tertiary times could be considered a regressive variant, but could not be considered an arrested variant. In Echini, cases of regressive variation are shown in the simple ambulacrum in *Melonechinus* (Plate 57, fig. 3), and in the single column of interambulacral plates in *Arbacia* (Plate 4, fig. 11) and *Tripneustes* (Plate 6, fig. 4).

4. *Parallel variation* is where a character is taken on exceptionally which may be compared with characters normally occurring in some type of the group not closely connected, so that it cannot be genetically compared. A case apparently is the extra genital pores frequently developed in Recent Echini (*Echinus*, text-fig. 115, p. 117).

5. *Aberrant variation* is where a character is taken on which is quite abnormal, not to be correlated with the typical condition in associated forms. Cases of aberrant variation are sea-urchins which have four or six areas developed (Plate 6, figs. 1-4). All the evidence goes to show that aberrant variation is rare, and most variants can be considered as arrested, progressive, regressive, or parallel variants, and as such can be correlated with species more or less nearly allied which typically possess the character which is a variant of the case in hand. This holds true as far as known in both animals and plants, as seen in the present paper, and as I showed in detailed studies of plants (1899).

Next to stages in development, variation is the most suggestive line of study in attempting to work out the genetic relations of plants and animals. When a specimen of one species

has characters approaching those of another, hybridity is often assumed as a cause. I have found numerous cases of variation to the character of another species where hybridity cannot be considered on account of geographical separation, and it is felt that we should be extremely cautious in assuming hybridity when the same results might be attained by variation. From my studies on Echini, all the evidence goes to show that variation is in perfectly definite lines, mostly arrested or progressive in character. When variation is aberrant, it still follows definite lines of aberration, and sporadic variation is very rare. This opinion is based largely on a detailed study of genital and ocular plates which were carefully examined in over 50,000 specimens of Echini (text-fig. 176, p. 153; p. 164).

To the late Professor Sven Lovén all students of the Echini owe a great debt for the keen eyesight and insight with which he studied these fascinating animals. His method was largely a critical detailed study of plate structure and relations, and this method I have attempted to follow in the study of Palaeozoic forms. Frequently sutures are so difficult to see and specimens are so contorted or badly preserved in these ancient forms, that I can hardly hope to have escaped mistakes; but this method has been followed out consistently and with every effort faithfully to describe and figure the specimens.

Lovén worked with Recent or post-Palaeozoic Echini, in which the axes are known from the presence of the madreporite as well as in many types by the bilateral symmetry. With known axes he devised a nomenclature of areas which is of very great value and convenience in brevity and clearness of description. He numbered the ambulaeral areas from I to V, Roman, and the interambulaera from 1 to 5, Arabic. The enumeration passed from left to right, revolving like the hands of a watch, with the specimen viewed from below and the odd anterior ambulaerum being III. This nomenclature is considered more fully under Morphology. It is readily seen in its application to *Goniocidaris* (Plate 2, figs. 1-3). In dealing with Palaeozoic types, there was usually no means of ascertaining the axes, for the madreporite was seen in only four species. Since, in the absence of known axes, Lovén's system could not be used, a system of nomenclature like that given in my earlier paper is followed. Taking any interambulaerum as A, the several areas are lettered from A to J inclusive, revolving like the hands of a watch, with the specimen viewed from the dorsal side. When a specimen is viewed from below, the letters naturally revolve in the reverse order. This is shown in its application to *Lovenechinus* (Plate 39, figs. 4, 5).

It may be well to call attention to the application of this nomenclature of areas to specimens viewed from different points so that it may be clearly in mind. External views, or internal molds, viewed dorsally: the axes revolve clockwise, from left to right (*Maccoya*, Plate 34, fig. 4; *Lovenechinus*, Plate 39, fig. 5). External views, or internal molds, viewed ventrally: the axes revolve anticlockwise, or from right to left (*Melonechinus*, Plate 55, fig. 1; *Lovenechinus*, Plate 39, fig. 4). In molds of the exterior, if dorsal: the axes revolve anticlockwise, from

right to left, as *Hyaltechinus rarispinus* (Plate 23, fig. 3) and *H. pentagonus* (Plate 25, fig. 3). In molds of the exterior, if ventral: the axes revolve clockwise, from left to right, as in *Hyaltechinus rarispinus* (Plate 23, fig. 1) and *H. pentagonus* (Plate 25, fig. 1). Orientation, not only for the sake of the axes, but also for the correct position and introduction of columns of plates and direction of imbrication, must be borne in mind in a reversed specimen; for naturally confusion results unless this is taken into consideration. It was a strong temptation to reverse the drawings, so that external molds seen from the interior might appear as if seen from the exterior. It would have simplified matters as regards orientation, but then the drawings would not have corresponded with photographic figures of the same specimen; also the complication is so great that I feared to make errors by reversing drawings.

The terms *molds* and *casts* are often used indifferently, but it is necessary to distinguish them. A mold, either internal or external, is an impression of a fossil and represents the object in reverse. A cast, either natural or artificial, is a mechanical filling of the mold and represents therefore a replica of the original. A pseudomorph differs from a cast simply in that it is a molecular chemical replacement of the original, as in silicification, instead of a mechanical filling of a mold, as in the case of mud, sand, or plaster. Most fossils, when they are not the original skeleton, are either pseudomorphs or molds; natural casts, strictly speaking, are comparatively infrequent.

In the figure of *Hyaltechinus rarispinus* (Plate 23, fig. 1) the test is wanting, and the view represents an external sandstone mold of the ventral side, together with an internal mold of the dorsal side, seen from above. The mold of the ventral side, being external, shows the tubercles and peripodia of the ambulacral pores, but the mold of the dorsal side, being an impression of the interior, has no tubercles, and the ambulacral pores are represented by vertical plugs. This shows that the point of view must be constantly borne in mind and orientation carefully considered. As an aid in orientation, a rubber ball was marked with ambulacral and inter-ambulacral areas, then cut down on these lines, and marked within. Also dorsal and ventral plaster molds of a *Cidaris* were made and lettered as models, for it was found difficult to keep orientation clearly in mind in reversed views, as are external molds.

An interesting matter is the condition of preservation of Palæozoic or other fossil Echini. I have never seen a fossil sea-urchin in which the test was preserved in its original condition, but rather some chemical change seems always to have taken place even in late Tertiary specimens. In other groups of animals, as fossil molluses, corals, etc., the original skeleton is often preserved without any change except the leaching out of organic matter. The sea-urchin skeleton is composed of such loose network-like structure, that it seems to be peculiarly open to chemical readjustment and change. When the skeleton is calcified, the original microscopic structure is, at least usually, quite destroyed. The skeleton is often replaced by silica, when we may get very beautiful pseudomorphs preserving the finest details; an example of this is *Melonechinus giganteus* (Plate 60, fig. 3).

One of the most interesting and instructive methods of preservation is when the surrounding matrix, both internal and external, is completely silicified and the original skeleton is entirely gone, but is represented in finest details by molds in silica. Such an example is shown in *Lovenechinus missouriensis* (Plate 39, figs. 4, 5). Here it is seen that everything that was not, is represented by the silica. This is rather a paradoxical statement, but fairly represents the facts. The plates are not preserved, but the sutures between the plates are represented by vertical siliceous ridges; the pores, both ambulacral and genital, are represented by vertical tubes, which can be actually seen (Plate 43, fig. 5) passing from the proximal to the distal side through the space which the plates originally occupied, but now simply a hollow. When the external as well as the internal matrix is in hand (Plate 44, figs. 3, 4), we find on one side, the internal matrix, a mold of the proximal side of the plates; on the other or external matrix we get the distal mold of the plates showing spine tubercles and other external features. Siliceous molds of the interior or exterior may be found in which there are no ridges representing spaces between the plates, but the difference of conditions between these two types is not understood. Molds, either internal or external, in fine sand or calcareous clay, are often extremely clear and may be accompanied by more or less of the shell of the test, or this may be wanting. In a specimen of *Palaeochinus quadriserialis* in the British Museum, the test is crystalline calcite, but only part of the plates are preserved; most of the rest are, however, represented by impressions of their proximal faces on the matrix, as shown in Plate 29, fig. 1, and Plate 30, figs. 1, 3.

Sandstone molds may be so fine in details of preservation as to show the outline of plates, tubercles, pores, and even peripodia. Internal sandstone molds show only impressions of the proximal sides of plates with pores in relief as slight plugs. An excellent example is *Hyattechinus beecheri*, a unique specimen (Plate 24, figs. 5-8), which shows the details of outline of the proximal faces of the plates so clearly that I am enabled in Plate 26 to represent the sea-urchin spread out, in which every plate was measured and the angles counted. External sandstone molds are even better, for, on the exterior, details of structure are more strongly marked; tubercles and peripodia exist as depressions (the impression being in reverse), and ambulacral pores as slight elevated plugs. Examples are shown in *Hyattechinus rarispinus* (Plate 23, fig. 1) and *H. pentagonus* (Plate 25, figs. 1-4). A curiously complex case is the *Hyattechinus rarispinus* previously mentioned (Plate 23, fig. 1), in which is seen an external mold of the ventral side, showing tubercles and peripodia, and in the same view an internal mold of the dorsal side. The counterpart of this remarkable specimen (Plate 22, figs. 1, 2) shows just the reverse condition; that is, an internal mold of the ventral side and an external mold of the dorsal side. The test, which was extremely thin, is mostly wanting, but is existent on the margins. The dorsal and ventral sides are brought almost in contact, yet the sandstone did not close up, but retained as a thin interspace the vertical space originally occupied by

the thickness of the test with some sand which filled the interior of the test, thus making an internal mold possible.

Lovén devised the incomparable method of representing the structure of a sea-urchin by a figure drawn from the ventral view and with the several ambulacral and interambulacral areas spread out flat in one plane in a star-like fashion. Of course in the Palaeozoic it is only rarely that one finds a fossil sufficiently perfect to admit of such treatment; but I give figures drawn by this method of *Bothriocidaris* (Plate 1), *Hyatttechinus* (Plate 26), *Archaeocidaris* (Plate 10, fig. 10), *Palaeochinus* (Plate 30, fig. 3), *Lovenechinus missouriensis* (Plates 40, 41), *Lovenechinus septies* (Plate 45), and *McLonechinus* (Plate 57). These genera are fairly representative of the several groups of Palaeozoic Echini, and the figures show the characters of the plates and the method of introduction of columns better than by any other method.

While perfect specimens are desirable and most highly prized, yet a great deal can be made out of fragments when studied carefully. A left or right half of an ambulacrum represents the character of the whole. A piece out of the mid-zone, that is, halfway between the mouth and middle of the periproct, represents the area where full specific characters are developed in both the ambulacrum and interambulacrum, and many species are represented by a figure taken from the mid-zone (Plate 47). Such a figure does not show the development as seen ventrally, or the apical disc, but these features are often wanting, or shown in related species, so that a figure of an ambulacrum and interambulacrum from the mid-zone gives for these areas the essential specific criteria.

The skeletons of Recent sea-urchins are often very fragile, and even if not so, the peristomal and periproctal plates are easily injured and lost. It has been found a great help to dip the specimens in, or brush them over with, a dilute solution of shellac in alcohol, or gelatine dissolved in water. Specimens so treated are firm and solid and will stand even rough treatment. A specimen with the spines all in place may be soaked in this manner by dipping, and on account of the porosity of the skeleton, there will be no external evidence of the treatment; the spines will be firmly fixed in place, and the specimen is in much safer condition for storage or study. Where sutures are difficult to see, as in minute recent material, or ambulacral details, it has been found a great help to wet them with benzole. When drying out, sutures stand out clearly that are nearly or quite unrecognizable in the dry state. In preparing fresh material of Echini, I have found that a satisfactory method is to soak the specimens over night in a considerable volume of fresh water to remove the salt, then immerse for a few minutes in boiling water containing a liberal amount of corrosive sublimate in solution. This treatment coagulates the albumen, poisons the specimens, and does not affect the color. They will dry out without odor, and in excellent condition as museum specimens. The method has the advantage of cheapness and quickness. When specimens are to be preserved in alcohol, the treatment with fresh water is also desirable, as it kills the animal nicely relaxed, besides removing much of the salt.

The theoretical views expressed in this paper are supported by a sufficient basis in facts, so that they appear reasonable to me; but I have endeavored to keep the descriptions of structural detail and the conclusions drawn from them distinct, so that the facts will stand for themselves, whether the deductions are accepted or not.

TERMINOLOGY.

Some new terms are made use of and old terms are not used uniformly by all investigators, so that the principal terms employed are given here in brief.

Test: the whole skeleton including the spines; or without spines, *denuded test*. Frequently *test* alone is applied to the skeleton in which spines are more or less wanting, the common condition in fossils.

Corona: the portion of the test, including the ambulaeral and interambulaeral plates, extending from the periphery of the peristome to the ventral margin of the apical disc. In describing an ambulaerum or interambulaerum, the terms *right* or *left* are frequently used. They mean the right or left side as seen facing the given area, viewed from the exterior and with the dorsal portion uppermost.

Ambitus: the zone of greatest circumference as viewed from above. The ambitus may coincide with the mid-zone, *Maeëya sphaerica* (Plate 32, fig. 5), or it may lie ventral to the mid-zone, *Hyattechinus beecheri* (Plate 24, fig. 7), or Clypeaster; or rarely dorsal to the median zone, *Lepidesthes coreyi* (Plate 66, figs. 8-10).

A sea-urchin is divisible into a series of *zones* which theoretically are as many as there are horizontal rows of plates, and each zone, at least in earlier life, differs or may differ in character from the preceding or succeeding zone. This is shown graphically in *Hyattechinus beecheri* (Plate 26); here in the first zone of interambulaeral plates there is one plate in each area, in the second zone two plates, in the third three plates, and so on up to the introduction of the full number of columns of plates, above which we reach zones of senescence, where plates begin to drop out. In practice, radial variation interferes somewhat with the perfect zonal expression, as all the areas do not develop with exactly the same degree of rapidity. For example, in *Lovenechinus missouriensis* (Plate 41, fig. 1), the fifth column originates in the fifth row above the initial plate of the fourth column in area A, whereas in the other areas it originates in the third or fourth row. Similar variations in rate of development are frequent in later added columns, as shown (Jackson and Jaggard, 1896) in detailed studies of *Melonechinus multiporus*, and as shown here in many figures. A column of plates may be quite wanting in one area, though developed in other areas of the same specimen. In *Hyattechinus rarispinus* (Plate 23, fig. 3) there are only eleven columns of plates in areas A and G, while there are twelve in area I and thirteen in C and E. In *Lovenechinus missouriensis* (Plate 41, fig. 1) the sixth column is represented by one or two plates in areas E, G, and I, but is wanting in A and C. A single zone is of course greatly modified in certain areas in bilateral types, as in ambu-

lacrum III in many spatangoids. Such extreme zonal modification does not occur in normal regular Echini.

The term *zones* has been sometimes applied as "ambulacral zones," but this seems an unfortunate use of the word, for such areas do not surround the test, as a zone should, and moreover are not parallel to the equator, which also the term commonly implies. Three main zones may be recognized in any sea-urchin, which I would designate as the basicoronal zone, mid-zone, and placogenous zone. In the *basicoronal* zone occur the basicoronal plates, the first row of ambulacral and interambulacral plates of the corona bordering on the peristome or buccal membrane. Lovén called these plates peristomal plates, but it seems an undesirable use of the word, which is usually applied to the buccal membrane and plates on the same. I therefore introduce the term *basicoronal* as meaning exactly what is intended, and not to be confused with terms applied to other parts. The basicoronal plates are of special interest as being the oldest or first formed plates occurring in any given corona, and also they are the plates giving support directly or through the perignathic girdle to important muscles of the lantern (text-figs. 22-31, p. 70; and 221-230, p. 193).

The *median zone*, or *mid-zone* for brevity, is that horizontal zone measured halfway between the poles; it may coincide with the ambitus or lie dorsal to it, or rarely ventral to it. The mid-zone is important in Palaeozoic and most other Echini, as the area in which in the ambulacra and interambulacra the differential specific characters are typically most fully developed. Ventral to it the full features may not have been attained, and dorsal to it we soon get into the area of localized development, where the young plates have not attained the full characters of the species. In clypeastroids and spatangoids that have petaloid areas, these lie dorsal to the mid-zone, so that in such types special consideration of the dorsal area is necessary, but it does not invalidate the mid-zone as an area of importance in the consideration of structure.

The *placogenous zone* ($\pi\lambda\acute{\alpha}\xi$ = plate, + $\gamma\epsilon\nu\epsilon\acute{\alpha}$ = birth) is that portion of the corona next to the apical disc in which the newly added coronal plates occur both in the ambulacrum and the interambulacrum. This zone is of importance as the plates in it quite generally present youthful characters, which, as localized stages in development, can be compared with the characters seen in the young, or in the adults of simpler types in the group (text-fig. 237, p. 231).

Row, as applied to ambulacral and interambulacral plates, refers to plates lying in one horizontal plane or zone, in contradistinction to columns.

Column, as applied to ambulacral and interambulacral plates, refers to plates lying superposed in a vertical series. The column is of course made up of nothing other than plates of a succession of rows, but is a convenient distinction to maintain in Palaeozoic types, where we find in various forms from two to twenty columns of ambulacral or one to fourteen columns of interambulacral plates. The column, especially in the interambulacrum, usually consists of a very definite succession of plates forced into a continuous series by the mechanical impact

of adjacent plates in the several succeeding rows. In the figures, the columns of interambulacral plates are numbered from one upward (Plate 57, fig. 1; text-fig. 246).

Adradial suture, a term introduced by Bather (1909a), is the suture between the interambulacrum and the ambulacrum. As a corollary, in Palaeozoic Echini, when there are more than two columns of interambulacral plates, those lying next the ambulacra are called the adradial plates. The term *adambulacral plates* or *columns* has been used, but the term *adradial* has the advantage of brevity.

Median suture is the suture in the median line of the ambulacrum. When there are only two vertical columns of plates, it is perfectly obvious, but when more, it is distinguishable by the size of the two medial columns, as in *Melonechinus* (Plate 56, fig. 4); or if the plates do not differ in size, it is distinguished by the fact that the pores in the plates are set on the side toward the next adjacent interambulacrum and therefore are set on opposite sides of the plates on either side of the median suture, *Lepidesthes wortheni* (Plate 67, fig. 8). The term *median suture* in Recent Echini is ordinarily applied also to the interambulacrum, and in Recent forms it is applicable, as there are two columns of plates; but, taking sea-urchins as a whole, it is not applicable to the interambulacrum; for it is only a coincidence of ordinal or specific character, if there is an even number of columns, and when there is, as in *Palaeochinus quadriserialis* (Plate 30, fig. 3), the suture in the median line is not distinguishable from any other interambulacral suture except the adradial.

In considering ambulacral plates, a certain degree of nomenclature is convenient. *Primary plates* extend from the middle of the ambulacrum to the interambulacral suture (Palaeochinus, text-fig. 9). *Demi-plates* extend from the interambulacrum inward, but do not reach the middle of the ambulacrum. *Occluded plates* extend outward from the middle of the ambulacrum, but do not reach the interambulacrum. Demi- and occluded plates are typically shown in *Lovenechinus* (text-fig. 11). *Isolated plates* do not reach either the interambulacral suture or the middle of the ambulacrum; such plates are extensively developed in *Melonechinus* and *Lepidesthes* (text-figs. 13, 14, p. 54). This nomenclature was based on the elements of compound plates in the Centrechinoida,¹ but it seems that it may equally be applied to the complex arrangement of simple plates in Palaeozoic Echini.

¹ The name *Diadema*, given by Schynvoet in 1711, cannot stand for a genus of echinoderms. The first post-Linnaean use of the generic name *Diadema* is in the "Museum Colonnianum," a dealer's catalogue published in London, in 1797; of this work, the author's name does not appear on the title page, but in the British Museum copy it is stated on two authorities that the author was G. Humphreys. There are 12 species listed under *Diadema*, but of these only one is recognizable, as it is stated to be the same as *Echinus esculentus* Linné. On this evidence, if this work should be accepted, which is very doubtful, the genus *Diadema* would become a synonym of *Echinus*, as *esculentus* is the type of that genus. The next post-Linnaean use of the name *Diadema* was by Schumacher, 1817, who gave this as a generic name for a cirriped, basing it on *Lepas diadema* Linné, which Schumacher (1817, p. 90-91) changed to *Diadema vulgaris*. This name is a synonym of *Coronula diadema* Oken (Lehrb. Naturg., 1815, part I, section 1, p. 360). Ranzani, in 1820, also used the generic name *Diadema* for a cirriped, adopting, as did Schumacher, *Lepas diadema* Linné, as the type and giving it the new name *Diadema candidum*.

A *simple plate* is one which has held its original character of one undivided and independent piece. All plates in Palaeozoic Echini are of this character.

A *compound plate* is one made up by the coalescence of adjacent plates, seen in the ambulacrum in certain groups, in which area alone is it known to exist. It is a character of the ambulacral plates in the Centrechinoida and some Holecypina, but is unknown in the Palaeozoic. The statement that compound ambulacral plates occur in Palaeozoic types has been made (Duncan, 1889a, p. 13), but it is an error; no such plates occur in any known type. Occasionally in regular Echini two genital plates, or a genital and an ocular, may fuse when the resultant may in a sense be considered a compound plate (text-figs. 186, 195, 196, pp. 168, 169).

Divided plates are those derived by the splitting on lines of solution of a previously continuous plate. This has been shown by Mr. Agassiz (1904) in the genital plates of Phormosoma. According to him (1904, p. 96), splitting occurs in interambulacral and ambulacral plates in Phormosoma. Mr. Agassiz (1874, p. 642) attributed the formation of compound ambulacral plates in the Centrechinoida, etc., to the splitting up of original plates. He also says (1883, p. 17) that anal plates in Palaeozoic Echini are formed by splitting. I have had this possible origin of plates in mind, but in my studies have seen no evidence of the origin of plates by splitting in Palaeozoic or other Echini excepting genital plates in echinothuriids, and rarely the same or ocular plates as variants (text-figs. 190-194, p. 169).

When the antero-posterior axis is known, Lovén's nomenclature of areas is adopted, numbering the ambulacra I-V and the interambulacra 1-5. In Palaeozoic species the axes are rarely known on account of the usual absence of madreporic pores. The axes are known from the presence of madreporic pores in *Lovenechinus lacazei* (text-fig. 240), *Lepidesthes formosa* (Plate 68, fig. 5), *L. colletti* (Plate 71, fig. 1), and *Meekechinus elegans* (Plate 76, fig. 1). Axes are assumed from bilateral symmetry in *Hyattechinus beecheri* (Plate 24, figs. 5, 8), from the orientation of primordial ambulacral plates, *Bothriocidaris archaica* (Plate 1, fig. 1), and from the apparently eccentric anal area, *Echinocystites* (Plate 20, fig. 1). In other Palaeozoic types the axes are oriented arbitrarily by letters A to J, as discussed in the Introduction.

Dr. Bather called my attention to a paper by McClelland (1840) in which he recognized that the name *Diadema* is not available for a sea-urchin, but he did not propose a new name. To quote his words, p. 170, "We luckily get rid of the genus *Diadema* [for Echini], from the term having been previously applied to a genus of Cirrhopoda by Ranzani."

High authorities reject Muerchen's (1774) names, therefore his *Anadema* is unavailable. The name *Calmarius annellata* is given by A. Agassiz (1872, p. 104) as a manuscript name of Gray's, and is treated by Agassiz as a synonym of *Diadema setosum*. As there is a closely related species, *Echinothrix calamaris* (*Diadema calamaris* Gray), it seems probable that Gray's generic name was *Calamarius*, taken from that species. *Calnarius* is evidently the same name as *Calamarius* with the letter *a* omitted by error; on this basis it is preoccupied by *Calamaria* Boie, 1827 (reptiles).

As a new name is thus necessary for this genus, I propose *Centrechinus* (κέντρον, a sting, and ἔχινος, sea-urchin) with *C. setosus* (Leske), from Key West, Florida, as the type. The Florida and West Indian *Diademas* are considered as *Diadema antillarum* Philippi by A. Agassiz and Clark (1908), but here *antillarum* is considered a synonym of *setosum*.

As the name *Diadema* cannot stand for an echinoderm, being preoccupied for a crustacean, the family and ordinal names derived from that genus cannot by the rules of nomenclature be retained. They can be replaced by names from the typical genus and may be called *Centrechinidae* and *Centrechinoida*.

The term *peristome* is not used in Lovén's sense, but in the more usual sense of the buccal membrane with its plates extending from the mouth to the basicoronal plates. The peristome may be more or less plated with ambulacral plates only, with ambulacral and non-ambulacral plates, with non-ambulacral plates only, or may be a naked membrane (text-figs. 40-54, p. 80).

Primordial ambulacral plates: these are the first formed ambulacral plates, ten in number, primarily situated around the mouth in the buccal membrane (Plate 3, fig. 11), or secondarily as basicoronal plates of the corona, as is usual in clypeastroids and spatangoids (Plate 3, fig. 15).

Primordial interambulacral plates: these are the first formed interambulacral plates, five in number, one in each area, which may be retained at the base of the corona in the adult, or may disappear by resorption (text-figs. 22-31, p. 70).

Ocular and genital plates are used in preference to radial and basal, as not implying a homology with those plates in erinoids. The sum of these plates may conveniently be termed the *oculo-genital ring*.

Gills are external and interrarial in position, situated on the border of the peristome, where they may well be called peristomal gills (text-figs. 55, 56, p. 83); or they are internal and radial in position, as Stewart's organs, Cidaris; or they may be external as modified tube-feet, when they may be called ambulacral gills to distinguish them from the interrarial peristomal gills.

The terminology applied to *spines* is necessarily rather arbitrary, as such great difference in size exists, but it is convenient to have some basis for description. Primary spines are the large spines occurring in such types as Cidaris or Arbacia. Secondary spines are best represented by the smaller spines clasping about the base of the large ones in Cidaris. Miliaries are minute spines seen between the smaller ones in Cidaris, or all the spines of Echinaraechnius could be classed under this head. These are spines so small that it requires a microscope to see their structure. In the Palaeozoic we find primary spines and secondary spines in Archaeocidaris (Plate 9, fig. 13) and Lepidocidaris (Plate 17, figs. 10-14). In some types secondary spines only are known, as in Melonechinus (Plate 52, figs. 10, 11) and allies. Miliary spines are so far known in Archaeocidaris only (Plate 11, fig. 4). The points of attachment of the spines are the tubercles which may be primary, secondary, etc., according to their size. The consideration of nomenclature of the parts of spines, plates, etc., of Echini is very clearly and definitely set forth by Bather (1909a).

The Aristotle's lantern is described as *inclined*, when in side view it subtends an angle of about 90°, the character of the Echinocystoida and Perischoechinoida (Plate 27, fig. 6); *erect*, when the faces of opposite sides are approximately parallel, the usual character of Recent regular Echini (Plate 5, fig. 2); and *procumbent*, when the flaring lantern rests almost on the base of the test, as in the Clypeastrina. Terms applied to the parts of the lantern are as follows. There are five teeth which are *grooved* or *keeled* (text-figs. 210, 212, p. 184). Each tooth is

embraced and held tightly in place by one of the pyramids, and proximally the soft growing end is enveloped by the *dental capsule* (Plate 5, figs. 1, 6). The pyramid dorsally includes a triangular space, the *foramen magnum*, which is *shallow*, or *deep*, and dorsally *open*, or *closed* by the lateral extension of the epiphyses (text-figs. 207–216, p. 184). The two *half-pyramids*, forming one pyramid and joined by suture, are *interradial* in position (text-fig. 211, p. 184); or the two *half-pyramids* joined by an interpyramidal muscle are *radial* in position (text-fig. 220, p. 191). These *radial half-pyramids* are a feature connected with the view of considering a sea-urchin as composed of five radial parts (pp. 62, 190, text-figs. 217–220). Each half-pyramid bears on its inner face an elevated ridge, the *dental slide*, which supports the tooth (Plate 2, fig. 10); and has a lateral wing that extends to the oesophageal cavity; on the outer face of the wing in regular Echini are *ridges* for the attachment of interpyramidal muscles (Plate 5, figs. 3, 5, 9). The dorsal face of a half-pyramid, seen when the epiphysis is removed, is described as *smooth* when no *pits* exist, Perischoechinoida, Cidaroida, or is described as having *pits* when such structures exist, Centrechinoida (text-figs. 208–213). Each half-pyramid is surmounted by an epiphysis, which is *narrow*, when it extends only slightly beyond the half-pyramid, or *wide*, when it extends across the foramen magnum uniting in median suture with its fellow of the opposite side (text-figs. 207–216, p. 184). Each epiphysis presents a *glenoid cavity* and *tubercles* for articulation with the brace, and in the Camarodonta *crests* for support of the tooth (Plate 2, fig. 14; Plate 5, figs. 2, 5, 9). The *brace* is a block-shaped plate and presents *condyles* and *foramina* which interlock with the *glenoid cavities* and *tubercles* of the epiphyses (Plate 2, figs. 9, 13, 15). In all regular Echini there are five *compasses*, each composed of two pieces joined by a transverse suture (Plate 2, fig. 12). The lantern muscles are termed *protractors*, *retractors*, *interpyramidal*, *brace muscles*, *circular compass* and *radial compass muscles* (Plate 5, figs. 1, 2, 4, 12; Plate 4, fig. 4; text-figs. 218–236, pp. 191, 193, 197).

The *perignathic girdle*, when existent, consists of processes arising from the basicoronal plates. *Apophyses* are upward growths of basicoronal interambulacral plates; *auricles* are here limited to separate pieces arising from the basicoronal ambulacral plates, to which they are joined by close suture, not being continuations of these plates as apophyses are of interambulacral plates (text-figs. 218–230, pp. 191, 193). The auricles in Phormosoma give rise to *radial somatic* and *radial peristomal* muscles, which are known only in the Echinothuriidae (text-fig. 226).

The diameter of the test in regular circular Echini, where the axes are known, is measured on the plane of the ambitus and passing through ambulacrum III and interambulacrum 5. In regular Echini, which are elliptical in horizontal outline (Echinometridae), or elongate irregular Echini, the length is taken in the longer axis and includes the over-all measurement of the corona.

PART I.

COMPARATIVE MORPHOLOGY OF ECHINI.

Having enjoyed the opportunity of studying most of the genera and species of Palaeozoic Echini, it is of importance to sum up the comparative structure and morphology of these types and to show their relations to living forms.

Palaeozoölogy is only one aspect of zoölogy, distinguished from the study of living animals about as embryology, a study of the young, is in so far separated from a study of adult organisms. As Huxley said, the only difference between a collection of fossils and a collection of recent animals is that one has been dead longer than the other. For an intelligent study of fossils their living representatives must be constantly borne in mind, as their details of structure throw a flood of light on fossil forms. Conversely a study of fossils in relation to the living gives a knowledge of the earlier and often primitive representatives of a group, throws light on the structure of the adult, and especially of the young of living types, and gives a rounding out of the knowledge of a group that cannot be attained by a study of the living forms alone. This is my excuse, if such is necessary, for including in this discussion representatives of living and other post-Palaeozoic Echini in the summing up of the relations and structure of the Palaeozoic types, with which this memoir is primarily concerned.

Under the consideration of Morphology are taken in order the form of the test, orientation, the pentamerous system and variation, the structure of the skeleton, and growth. In the sea-urchin there are many anatomical parts for consideration, and they are taken up in the following order: the ambulacrum and interambulacrum of the corona, basicoronal plates, imbrication, spines, peristome, ocular and genital plates, periproct, Aristotle's lantern, and perignathic girdle.

FORM OF THE TEST.

The general shape of the test of a sea-urchin varies greatly, but is more constant in Palaeozoic than in post-Palaeozoic types. The test may be elliptical with the vertical axis somewhat longer than the horizontal through the mid-zone, *Bothriocidaris*, *Palaeocchinus ellipticus* (Plate 29, fig. 2), *Lepidesthes colletti* (Plate 69, figs. 2-6). In Recent Echini the test is occasionally elliptical, as in *Amblypneustes formosus* Valentin, a species in which the height may exceed the diameter, though not always (A. Agassiz, 1873, p. 479). The test may be nearly or

- quite spherical, *Maceoya sphaerica* (Plate 32, fig. 5), most species of *Lovenechinus* and *Melonechinus* (Plate 55); or depressed spheroidal, as in *Archaeocidaris* and *Cidaris*.

In all the above types the ambitus coincides very nearly with the mid-zone. The horizontal section in any zone may be nearly or quite circular, or modified by more or less pronounced melon-like ribs or elevations of both the ambulaera and the interambulaera, as in *Melonechinus* (Plate 60, fig. 3). The test may be depressed spheroidal with ambitus below the mid-zone, as in *Lepidocentrotus whitfieldi* (Plate 19, figs. 6, 7), or recent *Strongylocentrotus*. Rarely the ambitus is above the mid-zone, as in the high obovoid *Lepidesthes coreyi* (Plate 66, figs. 8-10) and *Melonechinus obovatus* (Plate 54, fig. 2). As far as I am aware, this character of ambitus above the mid-zone is known otherwise typically only in the recent depressed *Echinostrephus molare* (Blainville), in which Mr. Agassiz (1873, p. 457, Plate 5a, fig. 11) showed that the greatest diameter is near the abactinal surface. It may occur occasionally as a variation, as I found in three specimens of *Strongylocentrotus purpuratus* out of 120, and in one specimen of *Strongylocentrotus dröbaehiensis* in 33,000. It is undoubtedly an exceptional character for the ambitus to be above the mid-zone in fossil or Recent Echini. The test may be depressed with strongly pentagonal outline, as in *Hyattechinus pentagonus* (Plate 24, figs. 1-4). It may be circular but greatly flattened dorso-ventrally, as in *Hyattechinus rarispinus* (Plate 22), which apparently closely approached *Echinarachnius* in form. Or finally, in Palaeozoic types, the test may be flat on the base with rounded dorsal side, of moderate bilaterality, almost Clypeaster-like in form, as in *Hyattechinus beecheri* (Plate 24, figs. 5-8). This includes all the forms of tests known in the Palaeozoic species.

The test may be radially equal with central periproct, as are most Palaeozoic Echini and most post-Palaeozoic regular Echini except *Echinometra* and allies. Or it may be bilateral with central periproct, *Hyattechinus beecheri* (Plate 24, figs. 5-8; Plate 25, fig. 5), a character not known to me in any other Echini. Or it may be more or less regular in form but with the periproct eccentric in an interambulaerum, which is probably the odd posterior interambulaerum, *Echinocystites*.

ORIENTATION.

The matter of orientation of a sea-urchin in relation to its true axis is important, and has been briefly touched upon in the Introduction. Lovén (1874) urged that the proper orientation of an echinoid is to take as the antero-posterior axis a line drawn through an ambulacrum and opposite interambulaerum, in such a plane that the madreporite lies in the right anterior interambulaerum. It seems rather arbitrary in the regular modern Echini at first sight, but there are good reasons for the acceptance of this orientation here. The most obvious reason, as pointed out by Lovén, is that it is morphologically the same line on which bilaterality is

developed in all the irregular Echini. The ambulacra fall into a posterior pair, the bivium of Lovén, and an anterior set of three, consisting of the right and left anterior ambulacra and the odd anterior ambulacrum, the trivium of Lovén.¹

It has been claimed that in regular Echini the madreporite is the only structure on which orientation could be based (A. Agassiz, 1881, p. 7). While this is apparently true in many Echini, I have attempted to show under the discussion of ocular plates that in many regular modern Echini a bilateral symmetry is expressed and orientation obtained by the order in which ocular plates reach the periproct. To state the case in brief: in the young of apparently all modern regular Echini, the ocular plates are exsert.² The same condition exists in the adult of many species. On the other hand, many species have in the adult one or more plates insert, or reaching the periproct, either as a typical character or as a variation. On the basis of observations on 50,000 specimens, the evidence is that the first oculars to become insert are the plates of the bivium, next the plates of the posterior pair of the trivium, and last, if at all, the anterior odd plate of the trivium. The order of reaching the periproct is I, V, or V, I, then IV, II, III. This order is very closely adhered to, as shown later in tabulated form. The ocular plates therefore in many regular Echini express a bilateral symmetry in this group, and an orientation passing through ambulacrum III and interambulacrum 5, the plane of symmetry adopted by Lovén.

As studied from the ventral view, Lovén (1874) showed graphically that the size and character of the primordial ambulacral plates give excellent data by which to orient a sea-urchin, at least in the Irregulares and often in the Regulares as well. He showed that of the ten basicoronal ambulacral plates in (typical) clypeastroids and spatangoids, the Ia, IIa, IIIb, IVa, Vb are larger, and in spatangoids possess two separate pairs of pores, or two separate single pores, indicating two tube-feet. On the contrary, the Ib, IIb, IIIa, IVb, Va are smaller, and in the spatangoids bear only a single tube-foot, Collyrites (Plate 3, fig. 15). This system of alternation has but this one combination, a sort of key, by which the axes can be ascertained with entire certainty, as shown in numerous genera and species (Lovén, 1874). Mr. A. Agassiz shows the same characters in his splendid work on Panamic Echini in numerous spatangoids as well as in many regular Echini.

Lovén (1892) showed that in the primordial ambulacral plates on the peristome in young *Goniocidaris* (Plate 2, fig. 1) the same system of alternation of large and small plates prevails. He (1874) also showed that it exists in the primordial plates surrounding the mouth in adult

¹ Mr. Agassiz (1881, p. 7) objected to Lovén's orientation as it does not take account of the madreporite in relation to the spiral system of development of plates. The spiral system was first suggested by Professor L. Agassiz (1834) and is considered by A. Agassiz in several publications (1864, p. 12; 1874, pp. 640, 722, 724; 1881, p. 7; 1892, p. 95). I regret that I have not succeeded in recognizing the spiral arrangement of plates in Echini.

² It is possible that in *Aspidodiadema* and close allies the oculars are insert from their earliest stages.

Cidar. Mr. A. Agassiz (1904) in the Panamic Echini shows the same system in young *Porocidar* *cobosi* A. Ag. (his Plate 12, fig. 2), young *Salcnocidar* *miliaris* A. Ag. (his Plate 16, fig. 1), young *Phormosoma* *placenta* A. Ag. (my Plate 3, fig. 10). He also shows the interesting fact that the same order of ambulacral plates exists around the mouth in the adults of *Cidar* (*Dorocidar*) *panamensis* (A. Ag.) (his Plate 3, fig. 4), *Porocidar* *milleri* A. Ag. (his Plate 7, fig. 6), *Echin* *soma hispidum* (A. Ag.) (his Plate 41), *Phormosoma* *zeylandiac* A. Ag. (his Plate 50, fig. 1), and *Kamptosoma* *indistinctum* A. Ag. (his Plate 50, fig. 1).

It is true that in the adult of most of the regular Echini, where the primordial ambulacral plates surround the mouth, usually more or less isolated, they have not retained the relative proportion of the Lovén system seen in the young, and from them one could not orient a sea-urchin. This has been dwelt upon at some length because in my studies of *Bothriocidar* *archaica* (Plate 1, fig. 1) it was found that the ambulacral plates around the mouth are arranged according to the Lovén law, which shows that it already was at work in the oldest known sea-urchin. It is worth mentioning that I was ignorant of the law at the time the drawing was made so that no prejudice came in to influence the making of the drawing.

Lovén maintained that the sea-urchin could also be oriented by the relative size and position of the ten interambulacral plates found at the base of the corona in regular Echini, the 1a, 2a, 3b, 4a, 5b plates being smaller, the 1b, 2b, 3a, 4b, 5a larger. This is often true, but often not true, and it seems that the law has no general application. Lovén's laws of orientation were carefully studied to see if correct orientation could thus be obtained in the Palaeozoic types, but with the exception of *Bothriocidar* without success. In Palaeozoic genera, as far as known, ambulacral plates always extend on to the actinostome as far as the mouth, as shown in *Bothriocidar*, *Hyattechin*, *Pholidechin*, *Melonechin*, and *Lepidesthes*, and if sufficiently well preserved, the orientation by primordial ambulacral plates might be applied, as in *Bothriocidar*. This, however, must await future study.

In the cases of *Lepidesthes* *formosa* (Plate 68, fig. 5), *L. colletti* (Plate 71, fig. 1), *Meechin* *elegans* (Plate 76, figs. 1, 6), and *Lovenechin* *lacazei* (text-fig. 240), the specimens are correctly oriented by the presence of a madreporite. *Bothriocidar* *archaica* (Plate 1, fig. 1) is oriented by the relation of the primordial ambulacral plates; *Bothriocidar* *pahleni* and *B. globulus* (Plate 1, figs. 6, 9) by the large ocular plate which, as shown in *B. archaica*, overlies ambulacrum III. *Hyattechin* *beechei* (Plate 24, figs. 5-8) is oriented by the plane of bilateral symmetry through an ambulacrum and posterior interambulacrum. *Echinocystites* *pomum* (Plate 20, fig. 1) is oriented by the eccentric anal area situated in an interambulacrum, presumably the odd posterior. The other species of Palaeozoic Echini figured cannot strictly be said to be oriented, as the letters designating areas are selected arbitrarily in each specimen without regard to a definite axis, which is an unknown quantity. The letters are used simply as a convenience in description for reference to specific areas.

THE PENTAMEROUS SYSTEM AND VARIATION.

In echinoderms as a whole the pentamerous system is remarkably constant as a character. In cystoids, however, we may have less than five ambulacra, as in *Echinosphaerites*, which has three ambulacra, or more than five, as in *Caryocrinus*, which has many ambulacral parts. In starfishes many genera, as *Heliaster* and *Solaster*, have typically more than five areas, and in some that have five, variation is common. In brittlestars more than five areas occur rarely as a specific, and in one instance as a sexual character. In all other groups of echinoderms the pentamerous system is very constant in all genera, and is departed from only as an individual variation. This variation is quite common in blastoids and crinoids. In Echini amongst Palaeozoic species, no case is known of departure from the pentamerous system, and it is apparently rare in living Echini. Bateson (1894) gives thirteen cases of complete or partial reduction to four-rayed sea-urchins in several genera of post-Palaeozoic fossil or Recent Echini. He also gives two cases of six-rayed urchins, a *Galerites* and an *Amblypneustes*, and three cases in which there is a sixth ambulacrum only. Chadwick (1898) described a four-rayed *Echinus esculentus* Linné, in which, however, there were five teeth. Ritchie and McIntosh (1908) describe, very carefully, an *Echinus esculentus* with a partial reduction to four areas. Tower (1901) records an *Echinarachnius parma* from Woods Hole with one of the ambulacra imperfectly developed, and Hawkins (1909a) an *Amblypneustes* with two ambulacra incomplete dorsally. Osborn (1898) described a four-rayed *Arbacia punctulata*, de Loriol (1883) a partially six-rayed specimen of *Stomopneustes*, and Ribaucourt (1908) a completely hexamerous *Strongylocentrotus lividus*.

I have been fortunate enough to study 71 specimens of Echini with a complete or partial departure from the pentamerous system. Besides being curiosities, these show very interesting morphological characters. Sixty were discovered in an examination of about 50,000 specimens for the characters of the apical disc, so that the variants from the pentamerous system averaged a little more than one to a thousand. The variants are partially or completely trimerous, tetramerous, and hexamerous. They are numerically as follows: one *Eucidaris tribuloides* in 849 specimens, six *Arbacia punctulata* in 2,329 specimens, two *Echinus magellanicus* in 200 specimens, 38 *Strongylocentrotus dröbachiensis* in 33,000 specimens, one *Strongylocentrotus eurythrogrammus* in 56 specimens, two *Toxopneustes variegatus* in 1,043 specimens, five *Toxopneustes atlanticus* in 2,643 specimens, three *Tripneustes esculentus* in 703 specimens, one *Echinometra lucunter* in 754 specimens, and one *Colobocentrotus atratus* in 82 specimens.

As later discussed, the ocular plates seem to exert a controlling influence in the building up of the corona, as below and in immediate contact with the oculars originate the coronal plates, both ambulacral and interambulacral. In connection with each ocular is developed a whole ambulacrum, and, in addition, a half-interambulacrum on either side. That is, while

an ambulacrum originates on the ventral border of an ocular, each interambulacrum may be considered as composed of two halves, the plates of which originated on the left or right of the area in contact with the adjacent oculars (text-figs. 217, 218, p. 191). If this is true, then the loss of an ocular would cause a failure to develop of the plates that normally went with it, also an abnormal position of an ocular (Plate 7, fig. 2) should cause an abnormal distribution of the associated coronal plates.

The cases of departure from the pentamerous system are taken up in the order of their structural characters. They are described in at least one case of each class and other cases are noted. The cases fall under twenty more or less distinct combinations of characters, and to facilitate the distinctions, they are numbered under so many distinct heads.

Trimerous.

1. *Three ambulacra, interambulacra, oculars, and genitals, four teeth.*—A specimen of *Strongylocentrotus dröbachiensis* collected at Dumpling Islands, North Haven, Maine, measuring 5.5 mm. in diameter (R. T. J. Coll., 812), is the nearest approach to a completely trimerous sea-urchin known. There are three ambulacra and interambulacra throughout the corona. There are also three oculars and genitals. The oculars all reach the periproct, an extraordinary character in the species, but no rules can be expected to apply in such a freak. There are four teeth and eight primordial ambulacral plates in the peristome.

2. *Pentamerous ventrally, three ambulacra and five interambulacra dorsally, five oculars and genitals.*—It is quite a frequent occurrence for one ambulacrum to fail to reach the apical disc, but rarer for two ambulacral areas to drop out. In a specimen of *Strongylocentrotus dröbachiensis* from Dumpling Islands, 43 mm. in diameter (R. T. J. Coll., 813), the test is quite normal ventrally, but dorsally ambulacra III and IV drop out (similarly, but later than in Plate 7, fig. 4), so that interambulacra 2, 3, 4 come in contact dorsally and make a continuous series of plates. All five interambulacra continue to the apical disc. There are apparently five oculars, but III and IV are imperforate and merged in a series of split genitals. There are five genitals, but genital 3 is imperforate and much split up by secondary sutures. A *Strongylocentrotus dröbachiensis* from Frenchman's Bay, Maine (R. T. J. Coll., 907), which measures 53 mm. in diameter, is pentamerous ventrally but ambulacra I and V drop out below the mid-zone. All oculars are in place but I and V are imperforate. As a result of this structure interambulacra 1, 5, 4 are confluent dorsally and the six columns of plates of these three areas extend to oculars II, I, V, IV as usual.

A specimen of *Toxopneustes atlanticus* from Bermuda (R. T. J. Coll., 814) is quite similar. It is 52 mm. in diameter and ventrally normally pentamerous. Ambulacra III and IV fail to reach the apical disc by a distance of 10 mm., so that interambulacra 2, 3, 4 are in contact

dorsally. There are five oculars and genitals, but oculars III and IV are imperforate. An imperforate ocular is usual when an ambulacrum drops out (Plate 7, fig. 4) and evidently is a correlated structure. The same structure is shown also in a specimen of *Arbacia punctulata* from Woods Hole, Massachusetts (R. T. J. Coll., 815). It is a small individual, 22 mm. in diameter, and distorted. Pentamerous ventrally, the ambulacra I and IV drop out dorsally so that interambulacra 5, 1, and 3, 4 are in contact dorsally. Five oculars and genitals are in place dorsally but somewhat distorted. There are as an independent variation eight plates in the periproct of this specimen.

3. *Pentamerous ventrally, three ambulacra and interambulacra dorsally, three oculars and five genitals in place, two oculars out of place.*—An ocular or a genital may be wanting, but when present, they are almost universally in place in the apical disc. No case of a disjunct genital

TEXT-FIG. 1.—*Strongylocentrotus dröbachiensis* (O. F. Müller). Sullivan, Maine. Diam. 42 mm. R. T. J. Coll., 710. $\times 3.5$. Oculars I and IV with associated coronal plates displaced.

has been seen, but in two cases oculars are separated more or less widely from the apical disc (text-fig. 1, and Plate 7, fig. 2). In a *Strongylocentrotus dröbachiensis* (text-fig. 1) a curiously abnormal and instructive condition occurs. The test is pentamerous ventrally, but dorsally the terminations of two ambulacra and four half-interambulacra are disjunct from the apical disc. There are five genitals and three oculars in the apical disc, but two oculars, I and IV, have become separated from the oculo-genital ring. The system is the same as that described in *Toxopneustes* (p. 42; Plate 7, fig. 2), only, as the separation occurred later in life, the distance of the oculars from the apical disc is not so great as in the *Toxopneustes*. Ocular IV (text-fig. 1), is furthest removed. Ambulacrum IV is twisted dorsally, but extends ventrally as usual. The right half of interambulacrum 3 abuts against ocular IV, and the left half of interambulacrum 4 curls around dorsally so as to come in contact with the opposite side of ocular IV. The left half of interambulacrum 3 and right half of 4 extend to oculars III and V respectively as usual. A similar condition exists in the relation of the ambulacrum and half interambulacra to the misplaced ocular I. If the abnormality had occurred earlier in growth, this would have made a very striking specimen, but yet it elucidates the principles involved quite clearly. In this specimen it is clear that ambulacra I and IV, with the associated half interambulacra follow the oculars I, IV in their displaced position.

Tetramerous.

4. *Four ambulacra, interambulacra, oculars, genitals, and teeth.*—More or less completely four-rayed specimens are the commonest departure from the pentamerous system, yet completely four-rayed specimens were seen in only nine cases, all in three species. In a specimen of *Strongylocentrotus dröbachiensis* (Plate 6, fig. 9) there are four ambulacra, interambulacra, oculars, genitals, and teeth, and eight primordial ambulacral plates in the peristome. It is oriented by the madreporite and character of the bivium reaching the periproct, or insert, as it is here called, which is a strongly dominant feature of the species. Accepting this orientation, the absent parts are ocular IV and its associated parts, which are ambulacrum IV, the right half of interambulacrum 3 and the left half of interambulacrum 4. The missing genital may be either 3 or 4, which, it is perhaps impossible to say. Four other specimens of *Strongylocentrotus dröbachiensis* show the same structure. In all, the bivium is insert and the missing parts are the same as in the specimen just described. One of these specimens is from Dumpling Islands, Maine (R. T. J. Coll., 816), and measures 18 mm. in diameter. Two are from Frenchman's Bay, Maine (R. T. J. Coll., 908, 909), and measure 42 and 52 mm. in diameter respectively. The fourth specimen is from Truro, Massachusetts (R. T. J. Coll., 817), and measures 26 mm. in diameter. In this specimen the lantern is wanting, but there are eight auricles which indicate a four-parted lantern. Four specimens of *Microcyphus maculatus*,

from Mauritius, with complete or partially tetramerous tests, were found in 343 specimens examined in the Museum of Comparative Zoölogy by Dr. H. L. Clark. Three of them fall under the present head, with four teeth, eight primordial ambulacral plates, four ambulacral and interambulacral areas in the corona, four oculars and genitals. In one of the specimens two of the genitals are fused, and in one of them a genital is split into three parts.

An *Echinometra lucunter* from Jamaica, in the Museum of Comparative Zoölogy, is completely four-rayed, with four teeth, eight primordial ambulacral plates, four ambulacra and interambulacra in the corona, four oculars and genitals. The absent parts are ocular and ambulacrum I and genital 1, the left half of interambulacrum 1 and the right half of interambulacrum 5.

5. *Four ambulacra, interambulacra, and oculars, five genitals, four teeth.*— This structure differs from the last described only in that there are five instead of four genital plates. An example is seen in *Arbacia punctulata* (Plate 8, fig. 2; Plate 6, fig. 1). The specimen is small, 26 mm. in diameter, but is higher than usual proportionately, 19 mm. It is perfectly shaped, not abnormal in appearance. There are five genitals, the only pentamerous part of the animal observed, but there are only four genital pores, one being absent in the madreporite. The specimen is oriented by the madreporite and planes of arrangement of the periproctal plates. Only four oculars are present. The absent parts are ocular and ambulacrum II completely, also the right half of interambulacrum 1 and the left half of interambulacrum 2. The corona consists, therefore, of four ambulacra with three interambulacra and two half-interambulacra. There are four teeth, four pairs of auricles, and eight primordial ambulacral plates.

A second almost completely four-rayed *Arbacia punctulata*, from Woods Hole, Massachusetts, is in the American Museum of Natural History. This like the above is small, perfectly formed, not at all distorted. It measures 25 mm. in diameter through the ambitus and 18 mm. in height. There are five genital plates, but the madreporite has no genital pore, and lies in close contact with genital 3 just as the madreporite lies in contact with genital 1 in Plate 6, fig. 1. There are four oculars, ambulacra, interambulacra, and teeth throughout. The absent parts are ocular and ambulacrum III, the right half of interambulacrum 2, and the left of interambulacrum 3 (compare Plate 6, fig. 1).

A third specimen of *Arbacia punctulata*, from Woods Hole, in the Museum of Comparative Zoölogy, has a similar structure. It has four ambulacra, interambulacra, and oculars, but five genitals, one depauperate and imperforate. The wanting parts are ocular and ambulacrum I, the right half of interambulacrum 5, and the left half of interambulacrum 1. The teeth are wanting. The *Arbacia punctulata* described by Osborn (1898) is similar to the above three, the five genitals being the only pentamerous portion. In his specimen as gathered from the description and figure, the absent parts are ocular and ambulacrum I, the right half of interambulacrum 5, and the left half of interambulacrum 1.

In Yale University Museum a specimen of *Arbacia lixula* from the Mediterranean has four areas. It is one of a lot of four specimens (cat. no. 199). There are five genital plates, but only four oculars and four ambulacra and interambulacra which extend from the basiconal row to the apical disc. The lantern is wanting. The absent parts are ocular and ambulacrum I, the right half of interambulacrum 5, and the left half of interambulacrum 1; therefore the left half of interambulacrum 5 and the right half of interambulacrum 1 are in contact and form a single area (compare Plate 6, fig. 1). This area is wider than usual for an interambulacrum, and the plates bear more primary tubercles than usual, but the tubercles are spaced about as in other areas, and in normal specimens. This indicates, as shown in the reverse condition in *Tripneustes* (p. 47), that tubercles and spines are distributed at a given distance apart, rather than a given number to a plate, as a species character. Genital 1 is somewhat distorted. Professor Verrill (1909) has given an excellent photographic figure of this specimen.

A small specimen of *Strongylocentrotus dröbachiensis* (Plate 7, fig. 3) has much the same character as the above described *Arbacias*. The specimen is normally shaped except that it is unusually high, dome-shaped. It is 35 mm. in diameter and 24 mm. high. There are four ordinary genitals and a small plate between the madreporite and ocular I may be considered a depauperate and imperforate fifth genital. There are four oculars. The specimen is oriented by the madreporite and the two insert ocular plates which in this species mark the bivium. The absent ocular on the basis of this orientation is evidently that one which should lie between the madreporite and the depauperate genital next to it. The absent part of the corona is ambulacrum II, also the right half of interambulacrum 1 and the left half of interambulacrum 2. The lantern is wanting, but there are four pairs of auricles indicating a four-parted lantern. A similar structure occurs in a specimen of the same species from Dumpling Islands (R. T. J. Coll., 818). It is small, 15 mm. in diameter, not distorted, and completely four-rayed except for the five genitals. The madreporite has no genital pore. The missing parts are ocular and ambulacrum II, the right half of interambulacrum 1, and the left half of interambulacrum 2.

6. *Four ambulacra (but ten primordial ambulacral plates), four interambulacra and oculars, but five genitals and teeth.*—This combination was found in a specimen of *Strongylocentrotus dröbachiensis* from Dumpling Islands, 5.5 mm. diameter (R. T. J. Coll., 819). Being very young, all the genitals are imperforate except for the madreporic pores. Ocular I only is insert. The missing parts are ambulacrum and ocular II, the right half of interambulacrum 1, and the left half of interambulacrum 2. Surrounding the five teeth are ten primordial ambulacral plates. This indicates that it began life as a pentamerous individual, but no trace of a fifth ambulacrum is seen in the corona.

A second specimen with these characters occurs in an *Echinus magellanicus*, from Port

Gallant, Patagonia, in the Museum of Comparative Zoölogy. It has five teeth and ten primordial ambulacral plates, four ambulacra and interambulacra in the corona, four oculars, but five genitals. The wanting parts are ocular and ambulacrum V, the right half of interambulacrum 4 and the left half of interambulacrum 5.

7. *Four ambulacra, but five interambulacra, oculars, genitals, and teeth.*— In *Arbacia punctulata* (Plate 7, fig. 1) an ambulacrum is entirely absent, but otherwise the specimen is pentamerous. It is a small specimen, 22 mm. in diameter. Dorsally there are five genitals and oculars, ventrally five teeth and ten primordial ambulacral plates. There is no trace of ambulacrum IV in the corona. Interambulacra 3 and 4 have each two columns of plates which extend dorsally to oculars III, IV, V, as usual in columns of these two areas. In addition to the four columns, there are ventrally several plates representing a fifth column and one plate a sixth column. These extra columns cannot be referred with assurance to either areas 3 or 4, but were in all probability developed below ocular IV and serve as space fillers in the corona to occupy the place that would have been filled by ambulacrum IV if it had developed. This specimen superficially is suggestively like Palaeozoic Echini where four or more columns exist in an interambulacrum, the median columns being made up of plates which in general are hexagonal, and the adambulacra pentagonal. Here, however, the many columns are the result of the union of two areas, not one area as in the Palaeozoic.

8. *Five ambulacra, four interambulacra, four oculars (one with two pores), four genitals, five teeth.*— A very peculiar case is the *Strongylocentrotus dröbachensis*, Plate 7, fig. 5. The specimen is good sized, 50 mm. in diameter and 30 mm. high. It has a pronounced bulging on the median suture line of ambulacra I, II. There are four genitals and four oculars. One of the oculars has two pores, indicating the termini of the radial water tubes of the two subjacent areas. There are five ambulacra, but interambulacrum 1 is entirely wanting. The ambulacra I, II have each two columns of plates, but the Ib and IIa are very narrow columns. It is worth noting that on the line of sutural contact of these two areas the outer pore of each pore-pair lies above the inner one, the usual condition where an ambulacrum abuts on an interambulacrum. There are five teeth and five pairs of auricles.

A second specimen showing this same structure is a *Toxopneustes atlanticus*, from Bermuda, R. T. J. Coll., 895. It measures 62 mm. in diameter, and is not distorted. There are four genitals and oculars, but one of the oculars has two pores, as in Plate 7, fig. 5, indicating that the pores connected with the two associated ambulacral areas. There are five ambulacra, IV and V being in contact throughout, as interambulacrum 4, also genital 4, are entirely wanting. There are five teeth, but only eight gill cuts.

9. *Five ambulacra, four interambulacra, five oculars, four genitals, five teeth.*— A *Toxopneustes variegatus* from Boca Ciega Bay, Florida (R. T. J. Coll., 820), 52 mm. in diameter, has five ambulacra, but interambulacrum 5 and genital 5 are wanting. A *Strongylocentrotus*

dröbachiensis from Truro, Massachusetts (R. T. J. Coll., 821), 32 mm. in diameter, is similar, with five ambulacra, but interambulacrum and genital 5 are entirely wanting. Both specimens have five teeth. The condition in both is similar to Plate 7, fig. 5, excepting that there are two oculars covering the adjacent ambulacra V and I instead of one ocular with two pores. A third specimen showing this combination is a *Microcyphus maculatus* from Mauritius, in the Museum of Comparative Zoölogy. In this there are five teeth, ten primordial ambulacral plates, five ambulacra and oculars, but four interambulacra and genitals. Interambulacrum and genital 5 are absent, so that oculars and ambulacra V, I are in contact throughout.

10. *Five ambulacra, four interambulacra, five oculars, genitals, and teeth.*—This type like the last has an interambulacrum wanting, but differs in that there are five instead of four genitals. A *Strongylocentrotus dröbachiensis* from Calderwood Island, Fox Island Thoroughfare, Maine, measuring 34 mm. in diameter (Plate 5, fig. 16), has five complete ambulacra but only four interambulacra. Interambulacrum 1 is absent and ambulacra I and II are in contact throughout their length. There are five oculars and genitals, but oculars I and II are in contact and shut out genital 1 from contact with the corona. This is the only case of a genital dorsal to the oculars seen excepting in *Bothrioeidaris archaica* where it is a species character. Genital 1 in this case is very small and imperforate. There are five teeth, ten auricles, and ten primordial ambulacral plates.

11. *Five ambulacra ventrally, four interambulacra throughout, four ambulacra above the ventral border, four oculars and genitals, five teeth.*—This peculiar structure occurs in one specimen only, an *Arbaeia punctulata* (R. T. J. Coll., 881), kindly sent me from Johns Hopkins University through Dr. G. T. Hargitt. The specimen is 43 mm. in diameter, 31 mm. high, and quite symmetrical. There are five teeth and ten primordial ambulacral plates, but only eight peristomal gills. At the ventral border of the corona there are five ambulacra, but ambulacrum II exists for only a distance of 2 mm. in which there are three pore-pairs. Above this point the ambulacrum is entirely wanting. There are four interambulacra only, the area lying above ambulacrum II being a complete area, but consisting of the left half of interambulacrum 1 and the right half of interambulacrum 2 (compare Plate 7, fig. 3). Dorsally there are four oculars, genitals, and periproctal plates. Ocular II has quite disappeared.

12. *Pentamerous ventrally, four ambulacra and interambulacra dorsally, four oculars in place (one ventral), five genitals.*—One of the most suggestive and interesting cases observed is the *Toxopneustes variegatus*, Plate 7, fig. 2. The specimen is full grown and has a strong bulge on the abnormal side. It is 61 mm. in diameter through III, 5; 67 mm. through 4, II; and 39 mm. high. Dorsally in place there are five genitals and four oculars, but just below the ambitus lies a fifth ocular which by some chance became separated and left behind during the dorsal growth of the sea-urchin. As there are the usual five areas ventrally, the specimen is readily oriented by the position of the madreporite. Ocular II, which should be between

genitals 1 and 2, has in its abnormal position grown to a large and somewhat irregularly shaped plate (compare oculars in text-fig. 1, p. 37). Below this ocular extends ambulacrum II, which finds its dorsal limit in this plate. Also extending ventrally from ocular II there are two half-interambulacra, the right half of interambulacrum 1 and the left half of interambulacrum 2. Proceeding dorsally from ocular II, the coronal plates that are typically associated with this plate cease, but the left half of interambulacrum 1 and the right half of interambulacrum 2 fill the space and extend respectively to ocular I and ocular III, their normal point of origin. There are five teeth. This specimen owes its peculiarities to relatively late influences, not congenital. It is similar in principle to text-fig. 1, p. 37, but is more striking as the ocular is farther removed from its normal position in the apical disc. It lends weight to the view held that ocular plates are a controlling influence in the development of the corona, and that from each ocular originates an ambulacrum and two half-interambulacra (compare text-fig. 218, p. 191).

13. *Pentamerous ventrally, four ambulacra and interambulacra dorsally, four oculars, and five genitals.*—A *Strongylocentrotus dröbachiensis* from York, Maine (R. T. J. Coll., 823), 40 mm. in diameter, is pentamerous ventrally, but ambulacrum II consists of only a pair of plates in the basicoronal row. The associated two half-interambulacra of areas 1 and 2 are similarly highly reduced. Above this extreme ventral area there are only four ambulacra and interambulacra. The ocular associated with ambulacrum II has quite disappeared, probably by resorption. Four oculars and five genitals are in place in the apical disc. Genital 1 is depauperate and lies against the madreporite. There are five pairs of auricles. A similar structure is shown in an *Echinus magellanicus* from the Straits of Magellan in the collections of the United States National Museum. There are five teeth and ten primordial ambulacral plates. In the corona there are five ambulacra and interambulacra ventrally, but ambulacrum I and the associated interambulacral plates exist for only a short distance, above which there are only four areas. There are four oculars and five genitals of which genitals 1 and 5 are depauperate and imperforate.

14. *Pentamerous ventrally, four ambulacra and interambulacra dorsally, four oculars and genitals.*—A *Strongylocentrotus dröbachiensis* from Dumpling Islands, Maine, (R. T. J. Coll., 824), 18 mm. in diameter, is completely pentamerous ventrally. A slight distance above the ventral border ambulacrum V drops out and also the two associated half-interambulacra. Ocular V has quite disappeared. There are four oculars and genitals in place. This type differs from the last considered only in that there are four instead of five genital plates.

15. *Pentamerous ventrally, four ambulacra and five interambulacra dorsally, five oculars and genitals.*—This is the commonest type of departure from the complete pentamerous system found, 17 cases having been seen. A small specimen of *Strongylocentrotus dröbachiensis* (Plate 7, fig. 4) shows interesting features. The specimen is 17 mm. in diameter, 9 mm. high,

and misshapen on the abnormal side. Ventrally there are five ambulacra, interambulacra, and teeth, but ambulacrum II is developed for a short distance only. Dorsally there are five genitals and oculars, but ocular II is imperforate. The dorsal border of the ambulacrum is widely separated from its ocular. Ocular II lies dorsally and produces its share of interambulacral plates, although ambulacral plates ceased to be built. Columns 1 and 2 of interambulacrum 1 extend dorsally and abut against oculars I and II as usual. In interambulacrum 2, columns 1 and 2 extend dorsally, but only 2 reaches the apical disc, column 1 dropping out, so that in the last three rows or zones of growth there is only a single column of plates in this area, a condition somewhat comparable to that seen in area 4 of *Arbacia* (Plate 4, fig. 11) where also a single column of plates exists dorsally. Just above ambulacrum II in this specimen (Plate 7, fig. 4) there are extra interambulacral plates that cannot be definitely referred to either areas 1 or 2. They are virtually space fillers, which, in my opinion, is what the interambulacral plates are. This specimen is structurally almost identical with the interesting *Echinus esculentus* described by Ritchie and McIntosh (1908). In both, the ocular remained in place dorsally but imperforate, the ambulacrum existed ventrally only, and the adjacent interambulacra developed in a comparable manner, though with certain differences. In the *Echinus* only the four columns of the two interambulacra exist above the imperfect ambulacrum, and extend dorsally to their respective three ocular plates.

A *Strongylocentrotus dröbachiensis* (Plate 6, fig. 6) has five oculars and genitals as usual; there are five interambulacra continuous to the apical disc, but one of the five ambulacra, IV, dies out dorsally, so that interambulacra 3 and 4 come in contact and alone touch ocular IV. The distance of separation of the ambulacrum from its ocular is only slight, but it represents a zone in which there are only four ambulacra. In this specimen ocular III is split, a rare variation, and genital 5 is divided. A few pores in the dorsal part of interambulacrum 3 are apparently supernumerary genital pores that lie below genital 3.

An *Arbacia punctulata*, from Woods Hole, Massachusetts, in the American Museum of Natural History, is peculiar in that ambulacrum III fails to reach the apical disc so that there are only four ambulacra in that region. The structure is almost the same as in Plate 6, fig. 6, except that a different ambulacrum is involved. Six specimens of *Strongylocentrotus* collected at Dumpling Islands, Maine, (R. T. J. Coll., 825-830), one from Calderwood Island, Maine (R. T. J. Coll., 845), one from Frenchman's Bay, Maine (R. T. J. Coll., 846), and two from Friday Harbor, Puget Sound (R. T. J. Coll., 903, 904), a *Strongylocentrotus eurythrogrammus* from New South Wales (R. T. J. Coll., 905), also a *Tripneustes esculentus* from Hayti (R. T. J. Coll., 831), and two specimens of *Toxopneustes atlanticus* from Bermuda (R. T. J. Coll., 894, 897), all show a similar structure to Plate 7, fig. 4, with five genitals and oculars in place and an ambulacrum dropping out at a greater or less distance from the apical disc. In all but one of these cases the ocular lying above the imperfect ambulacrum is imperforate. In the

several cases, each of the five ambulacra is involved, but IV appears to be more frequently imperfect than any other area.

16. *Pentamerous ventrally, four ambulacra and five interambulacra dorsally, four oculars, five genitals*.—This type is similar to that of 13 in that the ocular associated with an area has disappeared, but differs in that there are five interambulacra. A *Strongylocentrotus* from Calderwood Island, Maine (R. T. J. Coll., 832), 46 mm. in diameter, is completely pentamerous ventrally, but ocular II is wanting, and ambulacrum II falls short of the apical disc by 10 mm. The two bordering interambulacra, 1 and 2, are in contact dorsally. The dorsal plates of column 1, in interambulacrum 2 and of column 2, in interambulacrum 1 are large, not small as is usual in dorsal plates, indicating that no new ones have been recently added, which is in accord with the absence of ocular II, from which the plates of these two columns take origin. Three other specimens of the same species from Calderwood Island (R. T. J. Coll., 833–835) and a *Colobocentrotus atratus* from the Hawaiian Islands, in the State Museum at Albany, New York, have a similar structure. In all, an ocular is absent, and the corresponding ambulacrum falls short of the apical disc, but the associated interambulacra extend to the apical disc similarly to the specimen just described. In the *Colobocentrotus* noted, ocular I is absent, and ambulacrum I falls short of the apical disc.

17. *Pentamerous ventrally and throughout the corona, five oculars, but four genitals*.—This line of departure from the pentamerous system is where only one genital is absent. It is a typical condition in spatangoids where genital 5 is always absent, but occurs only as an aberrant variation in regular Echini. In *Eucidaris tribuloides* (text-fig. 185, p. 167) there are only four genital plates, 1 being absent. Oculars I and II are in contact, and as a result interambulacrum 1 comes in contact with two oculars as it does in *Bothriocidaris archaica* and in the posterior interambulacrum in spatangoids. This interambulacrum is also much narrowed dorsally and at one point a single plate fills the area laterally.

A more striking case is the *Arbacia punctulata* shown in Plate 4, fig. 11. In this remarkable specimen there are five oculars but only four genitals. Genital 4 is absent so that oculars IV and V are in contact. The interambulacrum 4 dorsally drops out to a single column of plates; the single column and the ocular contact of the dorsal plate of the same as a regressive variation is an exact repetition of the character seen in *Bothriocidaris archaica* (Plate 1, fig. 2).

A quite comparable case is seen in *Strongylocentrotus dröbachiensis* (Plate 6, figs. 7, 8). In this specimen there are five oculars, of which I and II reach the periproct and V, IV, III are exsert. There are only four genitals, number 4 being absent, so that oculars IV and V are in contact. These plates are peculiar in that they are produced ventrally in an elongate fashion. Interambulacrum 4 ventrally consists of two columns of plates as usual; above the mid-zone it narrows, and the two columns give place to a single column of plates for three rows, that is,

three plates (Plate 6, fig. 8). Above this point two columns are built again for a short distance, there being at this point three plates in column 1, and two in column 2. Proceeding dorsally, a change again occurs, and two single plates are built; the last is very high and narrow, unlike anything seen in any other echinoid. This structure is very difficult to see on the exterior of the test, but on the interior (Plate 6, fig. 8) it is perfectly plain. The dropping out to a single column is comparable to the typical character of *Bothriocidaris* and to the peculiar *Arbacia* (Plate 4, fig. 11). Dorsally, interambulacrum 4 does not reach the ocular plates, but is separated for a short distance in which ambulacra IV and V come in contact and alone reach oculars IV and V.

Another case was found in an *Arbacia punctulata* from Florida (R. T. J. Coll., 889, Plate 4, fig. 12). The specimen is 33 mm. in diameter. It is pentamerous throughout except for the absence of genital 4, which is wanting, as in Plate 4, fig. 11. It differs from that specimen, however, in that interambulacrum 4 is completely developed, its two columns extending, as usual, to the apical disc, but abutting against oculars IV and V without any contact with a genital as that plate is absent. Again, a similar structure is shown in a specimen of *Toxopneustes atlanticus* from Bermuda (R. T. J. Coll., 898). This specimen measures 53 mm. in diameter. It is quite pentamerous throughout except that genital 4 is wanting. Oculars IV and V are therefore in contact and cover completely ambulacra IV and V and interambulacrum 4 as in the *Arbacia*, Plate 4, fig. 12. In this *Toxopneustes* there are two columns of plates in contact with the two oculars, but the plates are small. These several cases demonstrate that the absence of a genital does not cause a loss of the corresponding interambulacral area.

Hexamerous.

18. *Six ambulacra, interambulacra, oculars, genitals, and teeth.*—In a fine large *Tripneustes esculentus* from Pernambuco, Brazil (Plate 6, figs. 2, 3) there are six arcs throughout, a condition hitherto definitely known only in *Strongylocentrotus lividus*. The specimen measures 110 mm. in all diameters as it is perfectly circular in outline. It is 58 mm. in height. In this species, when two oculars are insert, they are the bivium (see tabulation of 703 specimens, p. 161), so that the specimen is oriented on the basis of the insert bivium and position of the madreporite. Obviously the additional ambulacrum, ocular, and interambulacrum lie between interambulacrum 3 and ambulacrum IV. There are four normal genitals, but two, numbers 3 and 6, are fused into a single plate, a somewhat rare condition, but similar cases are seen in *Strongylocentrotus* and *Tripneustes* (text-figs. 195, 196, p. 169). There are six oculars, the sixth lying between the tips of genitals 3, 6. The ambulacra are all normal in appearance and at the mid-zone measure 28 mm. in width, except V, which is 29 mm. The width, 29 mm., is the same that is found in the ambulacra of a normal five-rayed specimen measuring

the same diameter of 110 mm. The interambulacra are normal in appearance superficially, but at the mid-zone they all measure 27 mm. in width, that is, they are narrower than the ambulacra. In a normal specimen of the same size the five interambulacra measure each 38 mm. in width when the ambulacra measure 29 mm. In the six-rayed specimen, therefore, evidently the space gained to add the extra ambulacrum and interambulacrum is attained by building ambulacra of practically the usual width, but narrowing all the interambulacra equally to much less than the usual width. This emphasizes the conclusion gathered from normal Echini that the interambulacrum is essentially a space filler and adapts itself to fill what space is available between the ambulacra which are the more essential structures. There are twelve cuts in the test ventrally for the peristomal gills, and the lantern has six teeth and all its other parts in sixes or multiples of the same. In the narrowed interambulacral areas the tubercles (Plate 6, fig. 3) occupy the same distance apart as in ordinary pentamerous specimens, but owing to the narrowness of the areas there are fewer tubercles on each plate. This case with the *Arbacia lixula* previously considered (p. 40) demonstrates that the distance apart and size of tubercles is the species feature and not the actual number of tubercles on a given plate.

The same hexamerous structure as just described occurs in a *Strongylocentrotus dröbachiensis* from Dumpling Islands, North Haven, Maine (R. T. J. Coll., 838, Plate 8, fig. 3). This choice specimen measures 53 mm. in diameter, and 25 mm. in height. There are six ambulacra and interambulacra complete, six oculars and six genitals, but genitals 3, 6 are fused, with ocular VI between them exactly as in Plate 6, fig. 2. The ambulacra at the mid-zone measure 11 mm. in width and the interambulacra 12 mm. In a normal pentamerous specimen of the same size the ambulacra measure 12 mm. and interambulacra 19 mm. in width. It is clear, therefore, that as in the Tripneustes, the space for the sixth areas is attained mainly by narrowing the interambulacra and retaining ambulacra of practically the usual width in all areas. Ventrally there are twelve cuts for the peristomal gills. Unfortunately the jaws are absent, but they were doubtless hexamerous as all other parts of the sea-urchin have this arrangement. I was startled by finding this same structure for a third time in a small *Strongylocentrotus dröbachiensis*, also collected at Dumpling Islands (Plate 7, figs. 7, 8). The specimen is 14 mm. in diameter and 6 mm. in height; it is perfectly shaped without any distortion. There are six ambulacra and interambulacra throughout the corona, six oculars and genitals, but as in the two other cases, genitals 3, 6 are fused, with ocular VI between them, as seen in Plate 7, fig. 7. It is certainly most extraordinary that this parallel structure should exist in three specimens, and indicates what I have elsewhere pointed out, how very definite even extremely rare variation may be. Ventrally there are six teeth, twelve primordial ambulacral plates around the mouth and twelve cuts for the peristomal gills (Plate 7, fig. 8). The three similar specimens of hexamerous Tripneustes and Strongylocentrotus just

described were evidently cases of congenital variation, whereas the next type considered is a variation to six parts taken on at a comparatively late stage in development.

The specimen of *Strongylocentrotus lividus* described by Ribaucourt (1908) would belong in this series, as he says that it is completely hexamerous, having six teeth, six ambulacral and interambulacral areas, six oculars and genitals. It would be interesting to know in which area the modification takes place and if there is a fusion of genitals as in the specimens above described.

19. *Pentamerous ventrally, six ambulacra and interambulacra dorsally, six oculars, five genitals*.—A most interesting condition occurs in a specimen of *Tripneustes esculentus* found in material kindly collected for me in Jamaica by Dr. Thomas Barbour. This choice specimen (Plate 6, fig. 4) measures 76 mm. through III, 5 and is 45 mm. in height; it presents a slight hump in the aberrant area. There are six oculars, but only five genitals. The additional sixth ocular lies between ocular II and the madreporite. Ventrally the specimen is pentamerous and quite normal, but above the mid-zone a sixth ambulacrum appears intercalated between ambulacrum II and interambulacrum 2. It extends dorsally, the two columns of plates reaching ocular VI in the usual fashion. About halfway, up the sixth ambulacrum a sixth interambulacrum appears. It consists of a single column of narrow plates which extend to oculars II and VI. The single column and ocular contact are comparable to the character seen in *Bothriocidaris archaica* (Plate 1, fig. 2). I believe it and the next described case are the only known instances since Ordovician times of an interambulacrum consisting of a single column of plates throughout its length. At two points the single column of interambulacral plates is separated dorso-ventrally, and at these breaks ambulacra II and VI are in contact for a brief space. Genital 3 is split horizontally, as in text-fig. 190.

A like partially hexamerous condition exists in a *Strongylocentrotus dröbachiensis* from Truro, Massachusetts (R. T. J. Coll., 836), 35 mm. in diameter. It is quite normal ventrally, but dorsally there are, as in the above case, five genitals and six oculars. Ocular VI lies between ocular V and genital 5 and is fused with the latter. A sixth ambulacrum for a length of 10 mm. lies between ambulacrum V and interambulacrum 5, the condition being as in Plate 6, fig. 4. A sixth interambulacrum, consisting of two plates in a linear series, lies between ambulacra V and VI as in the same figure.

A small and distorted specimen of *Arbacia punctulata* (R. T. J. Coll., 882) kindly sent me from Johns Hopkins University through Dr. G. T. Hargitt, again shows a similar structure. The specimen measures 36 mm. in diameter through 4, I and 19 mm. in height. Pentamerous ventrally, dorsally a sixth ambulacrum exists for a distance of 6 mm. The additional area lies between interambulacrum 1 and ambulacrum II (compare Plate 6, fig. 4). A sixth interambulacrum consisting of two plates in a vertical series lies between ambulacrum VI and ambulacrum II, as in Plate 6, fig. 4. There are six oculars and five genitals, but the latter are

confused by secondary sutures. There are six periproctal plates, probably a coincidence in number only as six plates in that area may occur in a perfectly pentamerous specimen (text-fig. 204, p. 175).

An *Echinarachnius parma*, from Chelsea Beach, Massachusetts, in the collection of the Boston Society of Natural History, no. 348, is another case of a similar structure. This specimen (Plate 8, fig. 4; Plate 7, fig. 9) is 59 mm. in diameter. It is not unusual in appearance except for the added areas. There are five ambulacra and interambulacra ventrally and nearly to the ambitus where the extra ambulacrum originates. The specimen is readily oriented by the position of the periproct in 5 (Plate 8, fig. 4) and also by the proportionate size of the primordial ambulacral plates (Plate 7, fig. 9), the Ia, IIa, IIIb, IVa, Vb, being the larger plates as usual, according to Lovén's law. The sixth areas as seen are late in development and occur between interambulacrum 1 and ambulacrum II. In the fused oculo-genital mass there are six ocular pores, one to each area as usual. There are, however, only four genital pores. One is wanting in 5 as usual, and also in 1, which is not usual. There is, however, a pore in the aberrant interradiar area 6. Ambulacrum VI originates just below the ambitus, has two columns of plates and a petal as usual, and differs only in that plates below the petal are smaller, and the petal is slightly narrower than in the other areas. Interambulacrum 6 originates slightly later than ambulacrum VI and differs from the other interambulacra only in that the plates are smaller. In this specimen the hexamerous variation was evidently not congenital, for as shown, a pentamerous condition was maintained for a time, expressed in terms of growth by the introduction of six horizontal rows or zones of ambulacral plates, as seen in area II (Plate 7, fig. 9). Above this zone the added sixth ambulacrum is introduced, and it, with the extra interambulacrum, is continued throughout succeeding growth to the apical disc.

20. *Pentamerous ventrally, six ambulacra, five interambulacra dorsally, six oculars, five genitals*.—This structure is shown in a specimen of *Strongylocentrotus dröbachiensis* from York Harbor, Maine (R. T. J. Coll., 847). The specimen is somewhat flattened, 27 mm. in diameter and 13 mm. in height. There are five ambulacra and interambulacra ventrally, but within 5 mm. of the peristomal border a sixth ambulacrum appears and is extended to the apical disc. The sixth ocular and ambulacrum lie between ocular and ambulacrum I and genital and interambulacrum 1. The relation is comparable to that shown in Plate 6, fig. 4, except that the two ambulacral areas are in contact, as in Plate 7, fig. 5, since there is no intervening interambulacrum. The genital plates in this specimen are considerably split by secondary sutures and somewhat distorted.

De Lorient (1883, Plate 4, fig. 3a) describes a partially hexamerous *Stomatopneustes variolaris* that is referable to this type of variation. I studied the specimen in Geneva. Ventrally there are five teeth, ten primordial ambulacral plates, five ambulacra, and five interambulacra. Dorsally there are six oculars and a sixth ambulacrum, but there are only five interambulacra and five genitals.

Bateson (1894) reports two cases of "total" hexamerous Echini. One is a *Galerites*, in which there are six ambulaera and interambulaera as seen from below; the dorsal portion and jaws are not shown. I have not seen Meyer's original paper where this was described. The other is a six-rayed *Amblypneustes*, but there is no description of the specimen. Bateson also records three specimens in which there is an accessory ambulaerum. These, with de Loriol's and Ribaucourt's cases above mentioned and the eight more or less completely hexamerous specimens here described, include all cases I know of in which there is an increase in parts over the typical pentamerous system in Echini. It is evidently a very rare variation.

Other variations from the normal have a certain interest. Four plates in the periproct is typical of *Arbacia punctulata*, but as later shown, variations of fewer or more than this number are common (text-figs. 200-205, p. 175). Variations in the number of genital pores are common, also as regards the distribution of madreporic pores. The variants of genital plates, or genitals and oculars, are all discussed later.

The above variations from the pentamerous symmetry can all be considered as monstrosities. Variation of another kind is more common, and interesting from another point of view; that is, variation in which the whole animal, or a part, is more or less fully developed in the direct line of the differential development or evolution of the species. This in Palaeozoic Echini is marked as radial variation, which was discussed in my earlier paper (1896, p. 151), and is shown in many cases here. An example is seen in *Lovenechinus missouriensis*, which has five columns of interambulaeral plates with often a sixth column represented by one or two plates near the mid-zone. In Plate 41, fig. 1, the sixth column is represented in areas E, G, I, but in areas A, C, there are only five columns. In the young specimen (Plate 40, fig. 1) there are five columns in four areas, but in area E the fifth column is represented by only a single plate, a great departure from the typical and a close approach to the character seen in lower species of the genus, as *L. lacazei* (Plate 36, figs. 1-6), which has only four columns of interambulaeral plates in an area as a specific character.

As shown in my earlier paper in detailed studies of *Melonechinus multiporus*, a given column of interambulaeral plates, especially the columns from 5 upward, may come in at varying zones in different areas of the same specimen, showing considerable variation in the rate of radial development. This is shown well in the zone of introduction of the seventh column in *Lovenechinus septies* (Plate 45, fig. 1). The actual number of columns, or differential character, may vary in different areas of the same specimen, as in *Hyattechinus rarispinus* (Plate 23, fig. 3). In *Melonechinus multiporus* (Plate 54, fig. 5) there are nine columns in area A, but only eight in the four other areas; in Plate 60 the specimen figure 2 has nine columns in all areas, but figure 1 has eight in all areas; Plate 55, fig. 3, has nine columns in areas C, E, and G, but the other areas are not known definitely; the specimen, Plate 55, figs. 1, 2, and Plate 57, has only eight columns in all five areas. A specimen may have but seven columns of inter-

ambulacral plates in an area, a rather rare variation in this species. This same variation of greater or less degree of radial differential development is shown in many species in this paper. The radial variation in a specimen may be as great as the variation of different specimens within the limits of a single species.

Variation is marked as regards the number of ocular plates that meet the periproct in Recent and some Palaeozoic Echini, as fully discussed later. Variation occurs all through Echini in all parts of the organism, and numerous cases are considered in the following pages. All the evidence goes to show that aberrant variation is relatively rare, and in almost all cases variation in Echini is either arrested, progressive, or regressive on the direct line of differential development of the given character in the ontogeny of the individual and the adults of associated species and genera. A variant in a species can, therefore, usually be compared either as a direct connection, or, if not that, as a parallelism with the typical condition in some other species of the group.

It seems that Echini are a particularly good group in which to study questions of variation because here variations can usually be expressed in very definite terms of numerical or other equally positive characters.

STRUCTURE OF THE SKELETON AND GROWTH.

The skeleton of a sea-urchin is made up of plates, spines, jaws, and other parts which are situated more or less deeply, and the skeleton is covered by living ciliated epithelial tissue. The plates and spines, while apparently external, are in reality included within living tissue. An exception to this covering of living tissue occurs in the primary spines of *Cidaris*, where, as Lang shows (1896, p. 389), a cortical layer is formed, and the integument dies away from the area covered by that tissue and persists only around the base of the spine. This may be compared with the velvet on deer's antlers, which, after the completion of growth, dies away, leaving the antler bare. The secondary spines of *Cidaris*, however, have no cortical layer, and are always covered by a ciliated integument, like a permanent velvet in antlers, and which is seen in the horns of the giraffe and okapi. This condition of the skeleton of Echini, of being covered by living tissue, is of fundamental importance to a proper understanding of the structure. As the parts are internal, they are capable of being added to or resorbed at any part throughout the life of the individual. This is true of all parts except the distal points of the teeth, which are truly external. The individual plate of the test grows by a constant addition to the exterior and resorption of the interior, which latter is composed of open lattice-like or trabecular tissue. The growth of a sea-urchin plate may be aptly compared to the growth of the head of a femur or similar bone with its hard dense exterior and open trabecular internal structure. Sectioning a sea-urchin plate, we find no trace of its earlier shape or character within, any more than we find the traces of a young femur within in sectioning the femur of an adult dog.

The mineralogical structure of the sea-urchin plate, as seen in a section of a plate of Recent *Strongylocentrotus dröbachiensis*, is crystalline calcite, with the axis of the crystal perpendicular to the surface of the plate, as shown by extinguishment under the polariscope. The plate is made up of a crystal which is optically continuous. Whether one, or more than one crystal enters into the composition of a single plate is doubtful, but it may perhaps be compared to ice on a pond, in which also the crystalline structure is optically continuous and the crystalline axis is perpendicular to the surface. It may be noted that the same crystalline structure, with axis perpendicular to the surface, was observed in the plates of *Synapta*, *Asterias*, and the calyx plates of a young *Antedon rosaceus*. In the stem of *Antedon*, however, the crystalline structure is parallel to the longer axis of the stem, not perpendicular to the surface.

While in the sea-urchin the corona grows by increase in size of the plates, often to a relatively great size, as in *Cidaris*, or the two plates in the second row of the posterior interambulacrum of *Micraster*, it also grows by the addition of new plates. In the corona, the new plates, both in the ambulacral and interambulacral areas, are always added dorsally, in immediate contact with an ocular plate. This holds good for Palaeozoic as well as later types; the only exception appears to be the aberrant *Pourtalesia jeffreysi* Wyville Thomson, in which, according to Lovén (1883), in adults, at least, oculars are apparently wanting. In *Bothriocidaris archaica* (Plate 1, fig. 2) it is seen that the ocular plates cover both the ambulacrum and interambulacrum entirely, and in all other Echini, as already stated, the oculars overhang the ambulacrum entirely and the interambulacra in part on either side, as in *Melonechinus* (Plate 56, fig. 6), and *Lovenechinus* (Plate 41, fig. 3). It is true that in many, perhaps most Echini, the interambulacral plates originate in contact with both the ocular and the genital plates in the angle between them, but they apparently never fail to come in contact with the oculars and they may not touch the genitals, as seen in *Bothriocidaris archaica* (Plate 1, fig. 2). In the posterior interambulacrum of *Ananchytes* (text-fig. 175) and in adult *Phormosoma placenta* (text-fig. 170) interambulacral plates originate against the oculars without touching a genital, and the same may often be seen in abnormal specimens as in area 4 of *Arbacia* (Plate 4, figs. 11, 12), and in the extraordinarily modified specimen of *Strongylocentrotus lividus* (Plate 6, fig. 5). It is striking in the Palaeozoic genera with many columns of plates that the new interambulacral plates originate against the oculars, *Lovenechinus*, Plate 41, figs. 2, 3, as discussed more fully later. What part, if any, the ocular plays in the origination of new plates is unknown, but at this area they originate. Mr. A. Agassiz (1904, p. 80) notes that in specimens of *Lovenechinus* (*Oligoporus*) *missouriensis* and *Lepidechinus imbricatus* the young interambulacral plates originate against the ocular. The specimen of *Lovenechinus* to which he refers is that figured in my Plate 42, fig. 6, and the *Lepidechinus* in my Plate 63, fig. 7, as *L. tessellatus* sp. nov.

The periproct grows by increase in the size of plates and the addition of new plates quite independently of the corona. The peristome grows in area by increase in the size of basicoronal

plates of the corona and in cases by resorption of the base of the corona. The plates of the peristome are various in origin. The primordial ambulacral plates of regular Echini are apparently in this area from their inception (Plate 3, fig. 7). Additional ambulacral plates are derived by flowing down from the corona (text-figs. 41-48, p. 80). All other peristomal plates, it is believed, are formed on that area and are not derived from the corona (text-fig. 57, p. 84). These matters will be considered in detail in their appropriate places.

THE AMBULACRUM OF THE CORONA.

The ambulacrum is the most essential feature of a sea-urchin, and has a first importance in classification and morphology, on account of the varied structure that it presents. We can conceive of a sea-urchin without an interambulacrum, although such is not known, or wanting in almost any other skeletal parts, but it seems that an ambulacrum is an essential character of the class. The detailed structure of the ambulacrum in post-Palaeozoic types is for the most part fairly well known, but the Palaeozoic types have not been closely studied, and throw a great deal of light on the structure of this area in the group as a whole.

The ambulacrum is essentially an area for bearing tube-feet, which are important as a means of locomotion in most Echini, or are modified more or less fully as organs of respiration in other Echini (clypeastroids and others). The ambulacrum is never composed of less than two vertical columns of plates, and when more than two, it always has an equal number on each side; therefore there is a distinct median suture with an equal area on each side of it. From this it follows that half an ambulacrum, barring exceptional variation, is as good as a whole one for study, which is important in fossils where one half is often all that is available. A partial exception to the rule of never less than two columns of ambulacral plates occurs in *Palaeotropus josephinae* Lovén, as figured by Lovén (1874, Plates 13, 32). In this exception, dorsally in all five areas the two columns drop out to a single column for a distance of three to seven plates from the oculars. This indicates that a sea-urchin might have a single column of ambulacral plates throughout at least the greater part of an area, but such is unknown. The width of the ambulacrum varies greatly. It is narrow usually, in types with low uniserial plates, *Eucidaris* (text-fig. 4), *Palaeochinus* (text-fig. 9); but it may be wide, as in the petaloid area of *Clypeaster*. The ambulacrum is wider usually when the plates are compound, *Strongylocentrotus* (text-fig. 5a), or when four columns, *Lovenechinus* (Plate 45), or more columns, *Melonechinus* (Plate 57), are developed. It may be much wider than the interambulacrum, *Lepidesthes colletti* (Plate 70, fig. 1), *Meekechinus* (Plate 76, fig. 1), and about twice the width of the interambulacrum in *Bothriocidaris* (Plate 1, fig. 1).

In the primitive type, *Bothriocidaris archaica* (Plate 1, fig. 1), the ambulacral plates are high, hexagonal, and there are therefore few tube-feet, about sixteen, to each area excluding

the two peristomal rows. In young *Goniocidaris* (Plate 2, figs. 1-3) the ambulacral plates are also high, hexagonal, and there are few tube-feet, about ten to each area. From this condition, which I would call primitive, increase of tube-feet or increase of locomotive power, is attained on three independent lines of development. First and simplest, by producing low plates with pore-pairs uniserial, so that many plates are contained in the vertical extent of the area, as in *Archaeocidaris* (Plate 9, fig. 6), *Eucidaris* (text-fig. 4), and *Palaeoechinus* (Plate 30, fig. 3). A second method of getting tube-feet is by increasing the number of columns of ambulacral plates from two to a greater number, but always by even numbers and always by simple, never compound plates (text-figs. 10-21). The increase is from two to four, six, eight, ten, twelve, sixteen, or twenty columns of plates in an area, which is the most at present known. This method is known in the Palaeozoic Echini only, and is especially developed in the Palaeoechinidae and Lepidesthidae. It is, however, taken up as a method in other types, as *Echinocyttites*. The third method of attaining increase of tube-feet is by building compound plates, formed by the coalescence of originally simple plates, *Centrechinus* (text-figs. 92, 94). The

TEXT-FIGS. 2-14.— Character of the ambulacrum in representative Echini; left half represented. The horizontal dotted line is on the plane of the mid-zone.

2. *Bothriocidaris archaica* sp. nov. Ordovician. From Plate 1, fig. 1.
3. *Goniocidaris canaliculata* A. Agassiz. Young. From Plate 2, fig. 2.
4. *Eucidaris tribuloides* (Lamarck). Bahamas.
5. *Strongylocentrotus dröbachiensis* (O. F. Müller). Young. From Plate 3, fig. 11.
- 5a. The same. Adult. York Harbor, Maine.
6. *Micraster cor-angineum* (Lamarck). Cretaceous, England.
7. *Echinarachnius parma* (Lamarck). Eastport, Maine.
8. *Metalia pectoralis* (Lamarck). Bahamas. Showing plates of two areas.
9. *Palaeoechinus elegans* M'Coy. Lower Carboniferous. From Plate 31, fig. 1.
10. *Maccoya burlingtonensis* (Meek and Worthen). Lower Carboniferous. From Plate 33, fig. 2.
11. *Lovenechinus missouriensis* (Jackson). Lower Carboniferous. From Plate 43, fig. 3.
12. *Oligoporus danae* Meek and Worthen. Lower Carboniferous. From Plate 50, fig. 7.
13. *Melonechinus multiporus* (Norwood and Owen). Lower Carboniferous. From Plate 56, fig. 4.
14. *Lepidesthes colletti* White. Lower Carboniferous. From Plate 70, fig. 3.

component elements of a compound plate are frequently low, but the plate as a whole is usually high. This method occurs in the Centrechinoida and is seen in some of the Holoctypina, but is unknown in the Palaeozoic. A good example is *Strongylocentrotus dröbachiensis* (text-fig. 5a), which at the mid-zone is characterized by compound plates composed of five or six component parts, each of which bears a pair of pores. As a very rare aberrant variant, pores may be wanting in such plates. In three specimens of *Strongylocentrotus dröbachiensis*, collected in Maine, the plates are compound, as usual, but in one area of each specimen the plates dorsally are somewhat distorted and have no ambulacral pores.

It must be strongly urged that the full character of the ambulacrum in a given type is to be based on the plates at the mid-zone. Below this point, or ventrally, they may not have attained the full differential characters, and dorsal to the mid-zone, one gets into the area of localized stages in development, where the young plates again have not taken on the full character; or again, one may also dorsally reach an area of senescent stages where the full characters are dying out. To illustrate this important principle, in *Maccoya burlingtonensis* (Plate 33, figs. 1, 2) the plates at the ventral border are all primaries and pore-pairs uniserial; at the mid-zone the plates are alternately primaries and occluded, and the pore-pairs biserial; dorsally, the young plates are again all primaries and pore-pairs uniserial. In *Lovenechinus missouriensis* (Plate 42, figs. 1-4) the plates ventrally are all primaries, at the mid-zone demi- and occluded, and dorsally again primaries. In *Melonechinus multiporus* (Plate 56, figs. 2-7; Plate 57; text-fig. 245) ventrally, plates are demi- and occluded; at the mid-zone demi-, occluded, and many isolated; close to the ocular, primaries only. In all of these series, and many others as well, the same system exists of simpler conditions ventrally in the plates built when the animal was young, and also in the nascent plates dorsally; and from there passing to the plates of the mid-zone, it is easily seen how the complex conditions there existent are built up. From these plates also one can arrive at genealogical relations, it is believed, of a very definite character (text-fig. 237, p. 231), as discussed later.

Of the Centrechinoida, in the young *Strongylocentrotus*, Lovén (1892) showed that the plates are simple with a single pore-pair (Plate 3, fig. 11). These plates in the adult are removed by resorption, but still the plates at the ventral border are unlike those of the mid-zone. At the dorsal border in *Strongylocentrotus*, as Lovén (1874) showed, and as Duncan (1885) showed in a number of types, the plates are simple, not compound. Duncan says (1885, p. 421), "It is an interesting and highly suggestive truth that all the regular Echinoidea should have their most radially situated plates in the form of the simple primaries of the Cidaridae." Lovén showed in *Strongylocentrotus dröbachiensis* that these simple plates are shoved downward and become fused to form the compound plates, characteristic of the species. At this region of young plates we find, therefore, as a localized stage, a simplicity like that of less specialized forms of Echini, as Cidaris. This character of dorsal simple plates is shown very well

in *Centreechinus* (text-fig. 94, p. 107), *Astropyga* (text-fig. 99), *Echinus* (text-fig. 115), and *Phormosoma* (text-fig. 170). Alexander Agassiz (1874, p. 642) said that the compound ambulacral plates are formed by the splitting of the original plates, but he was clearly mistaken. Passing dorsally, we may pass from compound plates into an area of simple plates which have dropped all attempt at fusion, as seen in *Hemicidaris* of the Jurassic (p. 17). Or, as A. Agassiz (1904, Plate 20, figs. 1-4) shows in *Salenocidaris miliaris* A. Ag., there is a single primary plate ventrally succeeded by one compound plate, which is again succeeded by simple plates throughout the area, a case of extreme reversion, in which simplicity is the dominant character, and compoundness or specialization is shown by only a single plate. This may be aptly compared to *Baculites* amongst the ammonoid cephalopods, in which its coiled (ammonite) character is reduced to a minute, almost microscopical basal portion, which is rarely preserved. Whatever the complexity of the ambulacrum in Palaeozoic or later types, it is striking that a simple condition obtains in the nascent plates of the placogenous zone. This all shows the fact of stages in development as evinced by the ambulacrum passing dorsally or ventrally toward the mid-zone, and the importance of differentiating zonal areas in the description of the ambulacrum.

While the regular Echini maintain a pair of pores in each ambulacral plate, or plate element in the case of compound plates, the case is different in the irregular post-Palaeozoic Echini. In the clypeastroids below the petaloid area, the ambulacral pores soon drop out, as in *Echinarachnius parma* (Plate 8, fig. 4), and the ambulacral plates for the most part at least are non-poriferous. It is true that there are very fine pores on the ventral side, as described by A. Agassiz (1874, p. 703), but these are so peculiar that they can fairly be distinguished from the usual pores of the ambulacral system. In spatangoids ventrally the pores may be wanting, or reduced to a single pore, instead of a pair of pores to a plate, in numerous cases.

As stated, ambulacral plates typically bear a pair of pores representing a single tube-foot, or the pair may be reduced to a single pore, as in some spatangoids. In spatangoids, however, we find a remarkable exception to the rule of a single tube-foot to a plate. In *Collyrites* (Plate 3, fig. 15) and other types, as shown by Lovén (1874), A. Agassiz (1904), and others, in the basicoronal row, the Ia, IIa, IIIb, IVa, Vb have two pairs of pores, and this is the only case of two pore-pairs, indicating two feet to a simple plate, known in Echini. Lovén thought it indicated a compound plate because of the two pairs of pores, or in cases two separate single pores, but always representing two tube-feet. The fact that no suture has been seen in these plates in any of this group of Echini militates against this view, and it seems best to consider this as a peculiar case of two feet to a simple plate rather than a compound plate, the suture of which has not been observed. As discussed under consideration of these plates (pp. 69, 71), the ambulacral plates in the basicoronal row of spatangoids and clypeastroids may reasonably be homologized with the first row of ambulacral plates found around the mouth in regular Echini and transferred to the basal row of the corona in the process of evolution of these spe-

cialized forms. In spatangoids, tube-feet as locomotive organs are largely abandoned, and they have only or mainly a respiratory function; here no compound plates are known. With a loss of the locomotive importance the plates below the petaloid areas, as in *Micraster* (text-fig. 6), are relatively high, even hexagonal, as in the embryo and the ancient *Bothriocidaris*. This primitive character of plates may exist in only one area. In *Metalia pectoralis* (text-fig. 8), for example, the plates at the mid-zone of the bivium and posterior pair of the trivium are low and wide, with pore-pairs horizontal. In the odd anterior ambulacrum, however, the plates are as high as wide, pore-pairs are superposed and in the middle of the plate, as in *Bothriocidaris*. In such plates we have often in the shape and height, also the superposed position of the pores in each pair, a condition which is a closer approach to the embryonic character and also to the character of *Bothriocidaris* than is seen at the mid-zone in the adults of any regular Echini excepting the ancient *Bothriocidaris*.

The position and mutual relation of the ambulacral pores is of considerable interest. It appears to be typical of the primitive and great majority of adult Echini to have two pores for each tube-foot, and the pair of pores to be surrounded by a more or less strongly marked peripodium. In many spatangoids the peripodium is absent. In all Palaeozoic genera there are two pores to every ambulacral plate and a peripodium is present apparently without exception (Plate 23, fig. 1). Of course it is such a slight eminence that it is very commonly worn off, but it has been found so widely that its frequent absence is attributed to conditions of erosion. In all Palaeozoic types and most modern Echini, the pores lie either in the middle of the ambulacral plate, which is rare, or nearer the next adjacent interambulacrum than the middle of the plate, which is the usual position. In no Palaeozoic type do they lie nearer the median suture of the ambulacrum than the middle of the ambulacral plate. In the demi-plates of *Echinosoma hispidum* (A. Agassiz, 1904, Plate 48) the pores lie nearer to the mid-suture than to the middle of the plates in which they occur. The same is true of occasional spatangoids, but is exceptional. In *Bothriocidaris* (Plate 1, fig. 1) the ambulacral pores of each pair lie in the middle of the plate, superposed dorso-ventrally, and surrounded by an oval peripodium, the axis of which coincides with the vertical axis of the area. In young *Goniocidaris* (Plate 2, fig. 2) the pores of each pair also lie superposed as in *Bothriocidaris*. From the superposed position, which may be called primitive, the position of the pores in all Palaeozoic types except *Bothriocidaris* and in most other regular Echini takes on a change in which there is a revolution through more or less of an angle of 90 degrees from the perpendicular, the revolution being in such a plane that the upper pore of the two is revolved toward the next adjacent interambulacrum. The revolution is therefore to the left of the perpendicular in the left half ambulacrum and to the right of the perpendicular in the right half-ambulacrum. Only rarely in regular Echini does the revolution exceed 90 degrees from the vertical, and in no case that I have found does the revolution take place toward the middle of the ambulacrum, but in the

opposite direction. From this it occurs that the pores of each pair occupy usually an inclined position, and the outermost pore of a pair is a little higher than the inner pore, Hyattechinus (Plate 23, fig. 1). It may be on a line with the inner pore, as in Melonechinus (Plate 61, fig. 8), but it is rarely lower than the inner pore in regular Echini. At the ventral border of the test the pores of each pair lie much more nearly vertical than at the mid-zone in Strongylocentrotus and Arbacia. In the latter the pores of the two pore-pairs adjacent to the median spheridium are actually superposed, as in Bothriocidaris. It is to be noted also that the pores on the peristomal ambulacral plates, as in Eucidaris (Plate 2, fig. 6), Phyllacanthus (Plate 2, fig. 18), Phorinosoma (text-fig. 43, p. 80), and Strongylocentrotus (text-fig. 50), are nearly or quite vertically superposed as in the young and in the primitive Bothriocidaris. Also it may be shown that in very young, newly formed plates next the ocular, of Goniocidaris (Plate 2, fig. 4), the plates are high, not low, and the pores are nearly or quite superposed. This is in a measure like the young of Goniocidaris (Plate 2, fig. 2) or adult of Bothriocidaris. I have seen the same character in very young plates of *Eucidaris tribuloides* close to the ocular.

In many clypeastroids, as *Echinarachnius parma* (Plate 8, fig. 4), the pores revolve through an angle of more than 90 degrees from the vertical, so that the outer pore of each pair lies lower than the inner pore. In many spatangoids the pores ventrally, and in most of the other ambulacral plates, are superposed as in the embryo and Bothriocidaris, but in the petaloid areas they are nearly or quite horizontal. In *Metalia pectoralis* (text-fig. 8) the plates in ambulacrum III are high, without petaloid expansion, and the pores are superposed in the middle of the plate; in the four other areas the plates are relatively lower, petaloid dorsally, and in these areas at least the pores are horizontal, not superposed, and not in the middle of the plates. From this it seems that the relative position of the pores represents a greater or less departure from the primitive, and that a more primitive or more specialized relative position of pores occurs at definite parts of the test in the same specimen.

In adult Bothriocidaris, Palaeochinus (text-fig. 15), and in the young, as seen in Goniocidaris, Strongylocentrotus (Lovén, 1892); also in the young, as shown at the ventral border of the test, in Maccoya (text-fig. 16; Plate 33, fig. 1) and Lovenechinus (Plate 42, fig. 1), we find that the pore-pairs in succeeding plates lie over one another in a continuous or uniserial system. This arrangement is certainly primitive. It is to be observed that in this condition all tube-feet extend to the ground from one continuous line, and when the plates are low, that they are proximally closely crowded as in Cidaris. From this condition of uniserial pores and tube-feet, we pass in many independent series to types in which the pore-pairs are biserial, triserial, or polyserial in each half-ambulacrum. This is accomplished by alternate plates failing to reach the interambulacrum in whole or in part, thus producing a biserial arrangement, Maccoya (text-fig. 16; Plate 33, fig. 1) and Lovenechinus (text-fig. 18; Plate 42, fig. 2). In addition isolated plates may be introduced to make a triserial arrangement of pores, *Melon-*

echinus springeri (text-fig. 19; Plate 52, fig. 2), *Perischocidaris* (Plate 67, fig. 1); or still more additional isolated plates may be introduced to make many series of pores in each half-ambulacrum, *Melonechinus multiporus* (text-fig. 20; Plate 56, fig. 4), *Lepidesthes colletti* (text-fig. 21; Plate 70, fig. 1), and *Meekechinus* (Plate 76, fig. 1). In the *Centrechinoidea* the pores of the

TEXT-FIGS. 15-21.— Ambulacra of Palaeozoic Echini showing development of pore series by a drawing-out process of plate movement.

15. *Palaeochinus elegans* M'Coy. Lower Carboniferous. Adapted from Plate 31, fig. 1. All plates reach the interambulacrum.

16. *Maccoya burlingtonensis* (Meek and Worthen). Lower Carboniferous. Adapted from Plate 33, fig. 1. Ventrally all plates reach the interambulacrum; further up, only alternate plates.

17. *Lovenechinus septies* sp. nov. Lower Carboniferous. Adapted from Plate 45, fig. 2. Ventrally all plates reach the interambulacrum; further up, every alternate plate. At the mid-zone the plates are as in text-fig. 18.

18. *Lovenechinus missouriensis* (Jackson). Lower Carboniferous. Adapted from Plate 42, fig. 2. Every second plate reaches the interambulacrum.

19. *Melonechinus springeri* sp. nov. Lower Carboniferous. Adapted from Plate 52, fig. 2. Every third plate reaches the interambulacrum.

20. *Melonechinus multiporus* (Norwood and Owen). Lower Carboniferous. Adapted from Plate 56, fig. 4. Every fifth plate reaches the interambulacrum.

21. *Lepidesthes colletti* White. Lower Carboniferous. Adapted from Plate 70, fig. 3. Every eighth plate reaches the interambulacrum.

compound plates tend strongly to fall into arcs in such fashion that succeeding pore-pairs fall in different vertical series, as seen well in *Strongylocentrotus franciscanus*. In *Diplocidaris* and *Tetracidaris* the pore-pairs, though in primary plates, are alternately pulled out of line, so that succeeding tube-feet would not lie quite over one another.

This passage from the primitive condition of monoserial pore-pairs to the biserial or polyserial, which is attained by the three methods of more than two columns of simple plates (Palaeozoic), compound plates with pores tending to arcs (Centrechinoida), or primaries with pore-pairs biserial (certain Cidaridae), is all in accordance with the mechanical principle of each tube-foot attaining fullest play by being out of line with its fellows in so far as is possible. The arrangement reminds one of the phyllotactic arrangement of leaves in plants, where each leaf is not succeeded by another in a vertical line until one or more have been added which are off that vertical line, but in a succession of lines of their own series.

In types, as spatangoids, in which below the petals the plates are relatively high and tube-feet therefore not crowded, the pore-pairs fall nearly in vertical uniserial lines, as in the young and primitive forms. This is aided probably by the fact that the ambulacral feet are for the most part modified as respiratory rather than locomotive organs.

Ambulacral plates on their proximal side differ from the same plates on their distal side, and this difference, as far as observed, is usually in the line of greater simplicity and relative primitiveness of structure. In *Melonechinus multiporus* (Plate 56, figs. 4, 5) and *M. giganteus* (Plate 61, figs. 5-9), the ambulacral pore-pairs distally are eccentric and lie nearest to the interambulacral suture, but proximally, as shown, the pore-pairs of isolated plates lie in the middle of each plate, a primitive character. In general the pores proximally are nearer the middle of the plate than on the distal side. In *Maccoya intermedia* (Plate 34, fig. 2) the plates alternately reach and are cut off from the interambulacral suture and pore-pairs are biserial. All this is as seen from the outer or distal side. When seen from the inner or proximal side (Plate 34, fig. 3), all the plates at the mid-zone cross the half-area instead of alternate plates being cut off from the interambulacral suture. Also the pore-pairs are uniserial instead of biserial, as they are on the outer side of the very same plates, so that in all these characters they are primitive like the young and the next lower genus *Palaeoecchinus* (Plate 31, fig. 1). A similar condition is seen in distal and proximal sides of the plates in *Maccoya burlingtonensis* (Plate 33, figs. 4, 5). In *Lovenechinus missouriensis* the outer demi-plates, as seen distally (Plate 43, fig. 3) are very narrow, the inner occluded plates are relatively wide and the pore-pairs of both lie very near the interambulacral suture. In a proximal view of the same plates (Plate 43, fig. 4) the demi- and occluded plates are of about the same width, and the pore-pairs of both lie near the middle line of the half-ambulacrum. Also proximally the plate that lies opposite the horizontal suture lines of the adradial plates is spread out in a fan-shaped manner, whereas on the distal side the fan-shape is nearly or quite wanting.

A similar condition of fan-shaped plates proximally, which are not so shaped distally, is seen in *Melonechinus multiporus* (Plate 56, figs. 4, 5) and *M. giganteus* (Plate 61, figs. 5-9). Comparable differences between the interior and exterior sides of the same plates are seen in interambulacral, ocular, and genital plates, as described in the consideration of these parts (pp. 75, 96, 172). All this shows that in the study of specimens and the description of species, one must bear in mind whether the specimen represents the internal or external characters of the test.

Another feature noticed on the inside of ambulacral plates is elevated nodose or spinose projections that occur in some Echini. These were first seen in the fossil Hyattchinus (Plate 24, fig. 6), where low, knob-like or spinose elevations exist between the inner pore and the middle of the area. Alexander Agassiz (1904, p. 31) has described spines extending into the body from the inner face of the peristomal ambulacral plates of *Porocidaris cobosi*, but I believe they have not been noticed before in coronal ambulacral plates. In Phyllacanthus (Plate 3, fig. 12) near to the ventral border of the test, there are small spines between the inner pores and the middle of the area; these seem to be the equivalent of those occurring in the Palaeozoic Hyattchinus. Close to the peristomal border these spines increase in height, arch over and then fuse in a continuous ridge (text-fig. 224, p. 193). Passing dorsally, in Phyllacanthus a second series of spines occurs, one over each inner pore, and above the ventral area these alone exist. In *Eucidaris tribuloides* I find a similar condition to that of Phyllacanthus, except that there are commonly three spinules over the inner pore (Plate 3, fig. 13). Such spinose growths are most delicate and are destroyed by a touch so that they can only be seen in a test cleaned without any brushing. They have not been noticed in any of the Centrechinoida.

Closely associated with the ambulacrum are the spheridia described by Lovén (1874), which, as he showed, are characteristic of all modern Echini except the Cidaridae. If they had existed in pits, as is so often the case, we might expect to find them in the Palaeozoic. The fact of their absence in the primitive Cidaridae is an argument for the assumption that they were also probably absent in Palaeozoic genera. Certainly they are not known.

Pedicellariae have recently come into prominence through the critical studies of Mortensen and others. It is of interest to note that tridentate pedicellariae occurred in the Palaeozoic, as shown in *Meekechinus elegans* gen. et sp. nov. (Plate 76, figs. 8, 9). Except as shown in the Jurassic Pelanechinus by Groom (1887) I believe these are the first found fossil, and they will probably always remain rarities.

Special respiratory organs are also closely associated with the ambulacra. Charles Stewart (1879) first described internal branchiae in *Eucidaris tribuloides* which lie dorsal to the lantern and extend over the ambulacral areas radially from beneath the compasses and between these and the braces. The same structures were described by Ludwig (1880) and by Prouho (1887) in *Cidaris papillata*. Prouho gave them the name of Stewart's organs, a convenient distinction from the quite different external gills. I have seen them in dissections of *Cidaris affinis*,

Eucidaris tribuloides and *thouarsii*. Stewart's organs are described in *Asthenosoma* by P. and F. Sarasin (1888), and in several echinothuriids by A. Agassiz and Clark (1909). External gills are developed as five pairs of branched appendages which are outgrowths of the oral integument (text-fig. 55, p. 83). They are characteristic of the Centrechinoida and by inference the fossil Holoctypina. Their presence is marked by the indenting of the interambulacral basicoronal plates so that they are recognizable in fossils. These peristomal gills, as I would call them for distinctiveness, are interambulacral in position in contradistinction to Stewart's organs, which are ambulacral or radial in position. In clypeastroids and spatangoids, as well as partially in some of the Centrechinoida (*Arbacia*), the function of respiration is maintained by the dorsal ambulacral tentacles, which have lost their function as locomotive organs. These I would call in distinction ambulacral gills. We do not and probably cannot know definitely what respiratory organs existed in Palaeozoic Echini. Branchial slits for peristomal gills I have found no evidence of, though carefully looked for. There is no evidence of specialization of tube-feet as ambulacral gills, though they may have performed that function in part. As the primitive Cidaridae have the Stewart's organs so well developed, it is not unlikely that these organs were the respiratory organs of all Echini in Palaeozoic times.

THE INTERAMBULACRUM.

The interambulacrum in Echini functions chiefly as a space filler and a bearer of spines and pedicellariae. The spines serve for protection and more or less in locomotion, and pedicellariae as grasping, cleansing, and protective organs. In spite of this secondary physiological importance, the interambulacrum forms a large part of the test of the sea-urchin in most types, and is of very great interest, especially in Palaeozoic genera.

The interambulacral plates originate in direct contact with the ocular plates and quite independently of the genitals. The young last added plates may always be found in direct contact with the oculars in Palaeozoic and later Echini, and their independence of the genitals is proved in cases where no genital reaches the interambulacrum, as in *Bothriocidaris archaica* (Plate 1, fig. 2), the posterior area in spatangoids (text-figs. 174, 175, p. 149), the aberrant *Arbacias* (Plate 4, figs. 11, 12), and *Tripneustes* (Plate 6, fig. 4). As any given interambulacrum comes in contact with two oculars, one on either side, and as at the base of these two oculars new interambulacral plates originate (*Melonechinus*, Plate 56, fig. 6, and numerous other figures), it seems that an interambulacrum may theoretically be considered as composed of two halves, one half-interambulacrum being associated with the ocular and ambulacrum on one side, and the other half being associated with the ocular and ambulacrum on the other side. In other words, the corona may be conceived as made up of five areas, each surmounted by an ocular plate, an ambulacrum and adjacent half-interambulacrum on either side making up each

of these five parts. Such an ideal area composed of plates associated with a single ocular is shown in *Palaeoechinus* and *Eucidaris* (text-figs. 217, 218, p. 191). Support for this view is found in the fact that the perignathic muscles of the lantern, which are nearly or quite ambulacral in position, are inserted wholly on the base of the associated two half-interambulacra, as in *Eucidaris* (text-fig. 218); or if not, they are inserted on two half-interambulacra and anricles of the ambulacrum itself, as in *Centreechinus* (text-fig. 219, p. 191).

In the *Echinothuriidae* where oculars and genitals are separated by an interspace, Mr. Agassiz (1883, p. 32; 1904, p. 96), says that the interambulacral plates are derived from the periproct, as the two areas are there in contact. Dr. Mortensen (1903, p. 175) opposes this view. Evidently this contact is a mere coincidence of structure and has no bearing on the origin of plates. In the *echinothuriids* which I have seen, the young interambulacral plates are in contact with the oculars as usual (text-fig. 170, p. 149). While in regular *Echini* outside the *Echinothuriidae* the oculars and genitals typically form a closed ring, yet occasionally in variants the ring may be open so that the periproct reaches the interambulacrum, as in *Strongylocentrotus* (Plate 5, fig. 15; Plate 6, fig. 5).

The full differential characters of the interambulacrum as of the ambulacrum are expressed at the mid-zone of the adult. Here are usually found the full number of columns of plates characteristic of the species, also the typical tubercles, spines, imbrication, or other characters which go to make up the specific description. The ventral border in the basicoronal zone represents the earliest formed plates and the youth of the individual, as far as it can be gathered from the study of an adult specimen, though the actually first formed plates may have been resorbed in development. Passing dorsally, with later added plates, new characters may come in until we get the full differential features developed at or about the mid-zone. Dorsal to the mid-zone we pass into the area of young last formed plates which have not yet acquired the full characters. Or again dorsally, we may find senescent features in the loss of columns of plates. Passing from the basicoronal row dorsally, we find in most Palaeozoic types, and many post-Palaeozoic as well, stages in development strongly marked, which stages can be correlated with the adult condition of simpler genera or simpler species within the genus. The interambulacrum in *Echini* has from one to fourteen vertical columns of plates in each of the five areas, which represents the least and greatest number known at present. There are intermediate grades representing every step between this least and greatest specialization of the area, and it is a matter of great interest to follow the progressive series as represented by stages in development, and by adult types, to see how the progressive differential structure is built up. As the plates of the ventral border are the oldest or first formed of any plates seen in an individual specimen, and as the later added plates succeed one another as we pass dorsally, it might be thought that we could read stages in development as expressed by rows and columns of plates with ease and certainty, and such can be done in many types, as in

Hyattechinus beecheri (Plate 26) and *Perischodomus biserialis* (Plate 64, fig. 2). Complications may come in, however, especially resorption of the base of the corona by encroachment of the peristome cutting off part of the ventral plates, and also rarely resorption within the corona, as exceptionally in *Arachnoides*, or differential growth of associated plates, which may separate plates originally in contact (*Echinarachnius*).

There may be few plates in a given interambulacrum, as in *Bothriocidaris* (Plate 1, fig. 1) or *Cidaris*, or a very large number, as in *Hyattechinus beecheri* (Plate 26), and many other species. There is every evidence that these plates all originated as separate plates and never by division of previously formed plates. Mr. Agassiz (1881, p. 95; 1904, p. 104) says that in *Phormosoma*, interambulacral plates are formed by the splitting of earlier continuous plates. Mortensen (1904, p. 25) suggests that these planes of division may be due to fracture in the handling of the specimens which have excessively thin plates, and my limited observations of *Echinothuriidae* accord with this view. If these are natural suture lines in *Phormosoma*, the numerous plates thus formed cannot be homologized with the numerous columns of plates in Palaeozoic types to which Mr. Agassiz compared them, for the latter originate independently, not by the splitting of previously continuous plates. While fusion into compound plates is seen in the ambulacrum of the *Centrechinoidea*, such fusion is unknown in the interambulacrum in all Echini. Lovén (1874, p. 51) assumed, it is true, fusion of certain plates around the base of the corona in spatangoids. No sutures exist, and it seems that single plates at this area in these and other types are not cases of fusion, but of failure to develop more than one plate in the row to which they belong.

In the important ancient type *Bothriocidaris*, as best shown in *B. archaica* (Plate 1, fig. 1), there is a single column of interambulacral plates in each area extending from just above the second row of ambulacral plates of the peristome to the apical disc, where in this species they are completely covered by the large ocular plates and do not reach the genitals. The full details of this and other cases given are considered under the description of the species. This is the simplest and, I think, the most primitive condition known in any adult echinoid. In my paper on Echini (1896, p. 233) I considered *Bothriocidaris* as representing the archaic radical as regards interambulacral structure from which the interambulacra in all other Echini could be derived. Further evidence and study confirm this view.

Mr. A. Agassiz (1904, p. 80) says, "The existence of an interambulacral zone composed of a single row of plates [in *Bothriocidaris*] does not give us any clue to the mode of formation of the Palaeochinid type of interambulacra with its manifold rows of plates." I cannot agree with this view, as it seems that the single primordial plate found so universally in young Echini, or in adults when resorption has not removed it, may fairly be considered as representing in development a stage consisting of a single column which in all but *Bothriocidaris* is succeeded by additional columns during development, as shown in my first paper and in numerous cases

in this paper. Dr. Mortensen (1903) describes a very young *Hypsiechinus* (my Plate 3, fig. 6), in which the interambulacrum consists of but a single plate in each of the five areas.¹ In young *Echinus* (Plate 3, fig. 5) Bury (1895) figures a similar single plate, and Lovén (1874, Plate 17, fig. 49) figures a young echinoid in which there is only a single interambulacral plate in each area. This single plate, it seems, represents a single-column stage consisting of this one plate, and may fairly be homologized with the plate at the ventral border of the interambulacrum of *Bothriocidaris*.

Lovén (1892) showed that in young *Goniocidaris* (my Plate 2, fig. 1), also in *Strongylocentrotus* (Plate 3, fig. 11), and *Echinus*, at the ventral border of the interambulacrum there is a single plate which lies dorsal to the continuous row of primordial ambulacral plates. This plate is evidently the single first formed plate, and is homologized with the ventral plate of the interambulacrum in *Bothriocidaris*. In the young of the Recent Echini mentioned, the first plate is succeeded in the second row by two plates introducing the character of a second column, which is the next stage in differential development of the interambulacrum. A similar single first plate succeeded by two plates in the second row is shown by A. Agassiz (1904) in young *Salenia* (his Plate 21, fig. 1), young *Phormosoma* (my Plate 3, fig. 10), and in young *Arbacia* (his Plate 54, fig. 2). In later life, in regular Echini, as shown by Lovén, this single initial plate is usually resorbed by the encroachment of the actinostome, so that in the adult there are two plates on the peristomal border, as in *Cidaris* and most regular Recent Echini. *Arbacia* (text-fig. 227, p. 193) and *Phormosoma* (text-fig. 43, p. 80) are exceptions, for, as Mr. Agassiz showed (1904, p. 54, Plate 41), the single plate is retained at the ventral border of the adult in these genera. As Lovén (1874) showed in the clypeastroids and spatangoids, the plate is retained at the ventral border of the corona in most cases, as the corona is not resorbed by the encroachment of the peristome. There are certain exceptions to this, as later discussed.

Turning to Palaeozoic types, we find in *Perischodomus* (text-fig. 30, p. 70; Plate 64, fig. 2) that there is a single plate ventrally succeeded by two plates in the second row, as in young *Cidaris*, etc., but in the third row there are three plates, which introduces another stage in differential development, structurally an advance on that seen in *Cidaris* and all modern Echini. In the next row of *Perischodomus* there are four plates, and later a fifth column is introduced. In this type we see that a form with five columns of plates in the adult is built up by a series of stages starting with a single column represented by a single plate ventrally, and the succeeding stages are represented by additional rows or zones of growth progressively introducing new columns or new characters in differential development.

In *Hyaltechinus beecheri* (Plate 26) we find ventrally a single plate representing a single

¹ In his text Dr. Mortensen (1903, p. 89) calls this plate a genital, but he wrote me that this was an error, and in the second part of his *Ingolf Echinoida* (1907, p. 172), corrects the error, saying that these plates are the first interambulacral and the genitals are discernible on the abactinal side.

column of plates in each of the five areas. In the second row there are two plates, in the third three, in the fourth four, in the fifth five, and so on. There is not always a new column added in each new row or zone of growth in this species, but this is very nearly the case up to the maximum number of columns added, which is eleven. Dorsally the adradial columns 1 and 2 drop out, so that columns 3 and 4 come against the ambulacrals in further dorsal growth. The same series of stages of progressive development marked by adding columns, and regressive senescent stages marked by the dropping out of columns of interambulacral plates are shown in *Hyattechinus rarispinus* (Plate 23, figs. 1, 3) and *H. pentagonus* (Plate 25, figs. 1, 3). In this last species in senescence, several columns are dropped, so that close to the apical region there are ten columns instead of the fourteen characteristic of its full development near the mid-zone. *H. pentagonus* is also especially interesting, as it attains fourteen columns of plates in the adult in each area, the maximum specialization in this line of differential development of all known Echini. Yet as resorption has not removed any plates, we can trace the development from the simple ventral or young condition, represented by a single plate on the peristomal border, to the complex adult and senescent old age without a single gap in the series of stages in development. In other Palaeozoic genera a similar progressive individual development may be traced in which the single ventral plate is retained in the adult, as in *Pholidechinus* (Plate 28, fig. 1), *Pholidocidaris* (Plate 73, fig. 6), *Lepidocentrus* (Plate 20, fig. 7), and *Lepidesthes* (Plate 68, fig. 3).

The above represent Palaeozoic genera in which there is no ventral resorption of the corona, and therefore all the interambulacral plates, built during the life of the individual, are retained and can be seen in a well preserved adult individual. Such successive stages in the development of an interambulacrum can be fairly compared to studying the development of a cephalopod or other mollusc, as has been done so successfully by Hyatt and others, by tracing the characters from the umbo or original apex of the shell by a series of steps or stages to the completed adult or old-age individual, all worked out in a single specimen. There is the great difference, however, that in the mollusc the shell is external, in the sea-urchin internal, so that in the latter the plates have grown since first formed and may have suffered changes, but from their presence stages can be read.

Resorption, however, comes in in Palaeozoic as well as in post-Palaeozoic types. Studying genera representing the Palaeoechinidae, we find that there are two plates at the ventral border of the interambulacra in all cases where the ventral part of the corona is complete, as seen in *Palaeoechinus* (Plate 30, fig. 3), *Maccoya* (Plate 33, fig. 1), *Lovenechinus* (Plate 43, fig. 1), *Melonechinus* (text-fig. 25; Plate 56, fig. 2; Plate 57, fig. 1), and others. This character is explained by the fact that the single initial ventral plate, found so universally in young modern Echini, and retained ventrally in numerous fossil and living genera, has been resorbed in the advancement of the peristome, as in *Cidaris* and most modern regular Echini. Miss Klem

(1904, p. 3) criticizes this view and claims that there are more than two plates when the ventral area is complete. I can only say that Miss Klem is mistaken. I have never seen an exception. Two of the specimens here figured, showing this character of two plates ventrally, are from the Hambach Collection which Miss Klem studied and herself figured, but it is fair to state that they have been freed somewhat from matrix since she studied them. The specimens referred to are *Lovenechinus septies* (Plate 45, fig. 1 = Miss Klem's Plate 2, figs. 5a-5d) and *Melonechinus multiporus* (Plate 57, fig. 1 = Miss Klem's Plate 3, figs. 6a-6d). In *Palaeochinus quadriserialis* (Plate 30, fig. 3) there are two plates in the first row or zone, three in the second, four in the third (excepting in one area, C), and above the introduction of the fourth column no more columns are added, but all are continued to the apical disc. Lovén (1874, p. 39) made the acute observation that in Palaeozoic genera with multiple columns of plates, the adambulacral plates alone are continued from the peristome to the apical disc. This observation holds true of most of the family of the Palaeochinidae, as in *Palaeochinus* (Plate 30, fig. 3) and *Lovenechinus* (Plate 41, fig. 1). The statement, however, needs modification. In those types where there is a single plate at the ventral border, *Perischodomus* (Plate 64, fig. 2), obviously two columns do not reach the peristome. Also in senescence (*Melonechinus indianensis*, Plate 53, fig. 1), usually the two adambulacral columns drop out before reaching the apical disc; or in specialized types they may drop out very early, as in *Hyattechinus beecheri* (Plate 26) or *H. pentagonus* (Plate 25, fig. 3).

In the family of the Palaeochinidae the species have as a range from three to eleven columns of interambulacral plates. In the several species the early development is as in *Palaeochinus quadriserialis*, but in later growth additional differential characters are usually taken on. In a young *Lovenechinus missouriensis* (Plate 40) a fifth column comes in soon after the fourth, and in this specimen, which is very young and the only really young Palaeozoic echinoid yet known, the fifth column originates near the mid-zone. In an older individual (Plate 41, fig. 1) where many more rows of plates have been added dorsally, we find that the introduction of the fifth column has been relatively shoved ventrally by the later added plates. In addition, a sixth column is represented by one or two plates in three areas, E, G, I, but in two areas, A, C, no sixth occurs. This occurrence of a column represented by only one or two plates is very exceptional in Echini and suggests a disappearing part. In many specimens of the species it is entirely absent. In *Lovenechinus septies* the method of introduction of columns is well shown (Plate 45, fig. 1), as it is one of the best preserved specimens I have seen. In three areas the two plates are present in the basicoronal row, restored in the other two; from this point up or dorsally in the several areas the new columns come in quite regularly. In the very choice specimen of *Melonechinus multiporus* (Plate 57, fig. 1; text-figs. 245, 246) there are two plates ventrally in areas G, I, one of the two in areas A and C, and they are restored in areas where wanting, as indicated by dotted lines. Above this zone the introduction of columns is shown without the absence of a single plate in all five interambulacral areas.

In *Melonechinus multiporus* there are eight or nine, rarely seven, columns of plates in each area. In *M. vanderbilti* there are nine columns of plates, and in *M. giganteus* (Plate 59, fig. 14) there are eleven. The columns are all added in a perfectly definite method and are in this feature further developments of the system seen in *Palaeochinus quadriserialis*.

The progressive addition of columns as we pass dorsally from the single column ventrally to the two to fourteen columns dorsally, I believe, represents distinctly stages in development through which the animal passes in its growth, the progressive stages being comparable to the conditions seen in the adult of simpler genera or simpler species allied to the type under consideration.

The method of introduction of interambulacral columns was shown in detail by Jackson and Jaggard (1896) and Jackson (1896), but will be briefly stated here. In the Palaeochinidae and most Palaeozoic Echini, excepting those that have strongly imbricate plates, the plates of the interambulacrum are typically hexagonal excepting the adambulacral columns which are nearly pentagonal but crenulate or rounded on the adradial suture. While the plates are typically hexagonal, this symmetry is modified where new columns are introduced. The initial plates of columns above the third are typically pentagonal with an apex of the pentagon pointing ventrally, and an adjacent ventral plate on the left or right is heptagonal, the added side compensating for the one side short in the initial pentagon. An exception to this rule of pentagonal initial plates of columns is seen in the initial plate of the third column, which is typically hexagonal and is immediately succeeded by the initial plate of column 4, which is a pentagon, as seen in *Melonechinus multiporus* (Plate 57) and many other species. If by rare exception the initial plate of column 3 is not immediately followed by the initial plate of column 4, as in area C of *Lovenechinus septies* (Plate 45, fig. 1), then the initial plate of column 3 is also pentagonal. When odd-numbered columns, as columns 3, 5, 7, 9, 11, etc., are introduced, they are typically introduced in the middle of the area with an equal number of columns on each side of them, and also typically the heptagonal associated plate lies on the right ventral border of the initial pentagon. When even-numbered columns are added, as columns 4, 6, 8, 10, etc., they are typically added to the right of the center with one more column on the left than on the right. While this is the rule in the large majority of cases, there are frequent exceptions in which even-numbered columns are added on the left instead of the right of the center. As a concurrent character, the associated heptagonal plate in even-numbered columns typically lies to the left of the initial pentagon. Why this systematic position of columns and associated heptagonal plates should come in with such regularity is not obvious, but it is a very constant character, as shown by Jackson and Jaggard (1896, p. 163) who worked out the percentages of normal cases and variations. In the dorsal portion of the interambulacrum the plates are nearly or quite rhombic in outline and gradually take on the typical hexagonal outline, as they are pushed ventrally by later intercalated plates and come into mechanical contact with adjacent plates of their several associated columns (Plate 59, fig. 14).

Dorsally each interambulacrum comes in contact with a genital and two adjacent ocular plates, except in *Bothriocidaris archaica* (Plate 1, fig. 2) and in part in *B. pahleni* (Plate 1, fig. 6), and in the posterior interambulacrum of many spatangoids (*Micraster*), where the interambulacrum abuts against two ocular plates only (text-figs. 174, 175, p. 149). The interambulacrum also comes against oculars only in the remarkable variations in *Arbacia* shown in Plate 4, figs. 11, 12. The new interambulacral plates in Echini are formed against the ocular plates on either side of the area, never in the middle against the genital.

The relation of the interambulacrum to the ambulacrum in development is of much interest, and it seems may be expressed in terms of acceleration of development. In *Bothriocidaris* (Plate 1, fig. 1) two continuous rows of ambulacral plates surround the mouth, forming the peristome of that type, before reaching the initial plate of the interambulacrum in the third aboral row or zone. This character in *Bothriocidaris* is discussed in detail under consideration of that type. In young *Goniocidaris* (Plate 2, fig. 1) and in young *Strongylocentrotus* (Plate 3, fig. 11), young *Salenia* (A. Agassiz, 1904, Plate 21, fig. 1), and young *Phormosoma* (Plate 3, fig. 9), a single row of continuous ambulacral plates surrounds the mouth forming the peristome at that age, but the initial single plate of the interambulacrum appears in the second row which is the base of the corona, instead of the third row as in *Bothriocidaris*. In clypeastroids and spatangoids (*Collyrites*, Plate 3, fig. 15) the initial single plate of the interambulacrum appears intercalated between the plates of the primordial ambulacral row, which, therefore, are not continuous as in regular Echini, but discontinuous, and, moreover, do not form part of the peristome, but form with the primordial interambulacral plates the basicoronal row of plates of the corona proper.

CHARACTERS OF BASICORONAL PLATES.

Basicoronal plates are the oldest or first formed plates existent in any given corona, and unless plates have been removed by resorption, or by flowing down on to the peristome, as in the ambulacrals of cidarids, they are the actual plates formed at this area in the young animal. Therefore, as elsewhere discussed, they often present simpler characters than plates dorsal to them, and thus show stages in development. These plates on the proximal side give rise to the attachment of part of the muscles of the Aristotle's lantern, either directly or through the elevated processes of the perignathic girdle, which is later discussed. There are certain types of structure in basicoronal plates which are comparatively constant in large groups, so that they are of more than specific or generic value.

The characters of basicoronal interambulacral plates are the more striking and may be stated in brief. Where no plates have been removed by resorption, there is a single plate at the ventral border of the interambulacrum. The primitive type of this character is *Bothrio-*

cidaris (text-fig. 22), which continues to build a single column. This same character of a single plate ventrally, but succeeded by two plates in the second row, is characteristic of the young of all modern regular Echini, as shown by Lovén (1892) (*Goniocidaris*, text-fig. 23). In the adult of most regular Echini the single plate and probably more have been resorbed by the advance of the peristome (*Eucidaris*, text-fig. 24). In the Palaeoecchinidae with many columns of plates, apparently only one plate has been resorbed, when we find two plates in the basicoronal

TEXT-FIGS. 22-31.— Characters of the base of the interambulacrum in representative Echini.

22. *Bothriocidaris archaica* sp. nov. Ordovician. From Plate 1, fig. 1.

23. *Goniocidaris canaliculata* A. Agassiz. Young. From Plate 2, figs. 1, 2.

24. *Eucidaris tribuloides* (Lamarek). Bahamas.

25. *Melonechinus multiporus* (Norwood and Owen). Lower Carboniferous. From Plate 57.

26. *Archaeocidaris wortheni* Hall. Lower Carboniferous. From Plate 9, fig. 6.

27. *Plexechinus cinctus* A. Agassiz. Adapted from A. Agassiz, 1904, Plate 58, fig. 1.

28. *Echinocyamus pusillus* (Müller). Adapted from Lovén, 1874, Plate 44.

29. *Rotula dentata* (Lamarek). Adapted from Lovén, 1874, Plate 46.

30. *Perischodonus biserialis* M'Coy. Lower Carboniferous. From Plate 64, fig. 2.

31. *Tiarechinus princeps* (Laube). Triassic. Adapted from Lovén, 1883, Plate 13, figs. 152, 154.

In figures 22, 23, 27-31 the primordial interambulacral plate is in the basicoronal row; in 24-26, it, with or without additional plates, has been resorbed.

row (*Melonechinus*, text-fig. 25), or in the *Archaeocidaridae*, several rows of plates may have been resorbed, and we find four plates in the basicoronal row (*Archaeocidaris*, text-fig. 26).

In modern Echini where there has been no resorption, the single primordial plate is retained in the adult. This character, as shown by Lovén (1874) and others, occurs in most clypeas-

troids and spatangoids (text-figs. 27-29). In *Plexechinus* (text-fig. 27) the single plate is followed by another single plate, and these by a second column. This is a very rare exception, as the typical character is for the initial primordial plate to be immediately succeeded by two plates in all Echini except *Bothriocidaris*. In *Rotula* (text-fig. 29) the primordial interambulacral plate is separated from the next two of its area by the lateral introvenient ambulacral plates. As shown by Lovén, plates originally in contact in the young may be thus separated during growth. A few modern regular Echini retain the primordial plate in the adult (*Phormosoma*, text-fig. 43, p. 80; *Arbacia*, text-fig. 227, p. 193).

In Palaeozoic Echini with imbricate plates and many interambulacral columns, there is no resorption, and therefore the primordial interambulacral plate is retained in the adult, as in *Perischodomus* (text-fig. 30), *Hyattechinus* (Plate 25, fig. 1), *Lepidocentrus*, *Lepidesthes*, and *Pholidocidaris*. The primordial plate in all these is succeeded by two plates, then three, then four, etc. (text-fig. 30). In the remarkable *Tiarechinus* from the Trias, Lovén (1883) showed that the primordial interambulacral plate is succeeded by three plates (text-fig. 31), and then no more plates are built, a unique condition.

Considering the general characters of the basicoronal row, with special reference to the ambulacral plates, we find the following types of arrangement. In *Bothriocidaris* the basicoronal row consists of two high hexagonal ambulacral plates with pores superposed in each ambulacral area and one interambulacral plate in each interambulacral area (Plate 1, fig. 1). This same character is seen in young cidarids (Plate 2, fig. 2) (Lovén, 1892; A. Agassiz, 1904), young *Strongylocentrotus* (Plate 3, fig. 11), and *Echinus* (Lovén, 1892), young *Salenia*, *Arbacia*, and *Phormosoma* (A. Agassiz, 1904). It is, I think, fair to call this a primitive character, and it represents what I (1896, p. 235) described as the *protechinus* stage. The *protechinus* stage is comparable in other groups of animals to the protoconch of cephalous Mollusca, what I (1890) described as the *prodissoconch* of Pelecypoda, and to Beecher's (1901) *protegulum* of Brachiopoda and *protaspis* of Trilobita. All are referable to what I termed (1890, p. 289) the *phylembryonic* stage in development, a stage in which the differential characters of the class are established in ontogeny.

A second type of basicoronal plates, in which there are two ambulacral plates alternating with one interambulacral plate in each area, is seen in types where the ambulacral plates have in part flowed down on to the peristome, so that the plates originally there are gone, and yet the primordial interambulacral plate has retained its original place. Such is seen in the Palaeozoic *Hyattechinus* (Plate 23, fig. 1), *Pholidechinus* (Plate 28, fig. 1), *Lepidesthes* (Plate 68, fig. 3), and Recent *Phormosoma* (text-fig. 43, p. 80). This last type differs markedly from those just considered in that the ambulacral basicoronal plates in the adult are compound instead of simple. No compound ambulacral plates on the peristome are known in any type.

A third type of basicoronal plates is seen in clypeastroids (*Echinarachnius*, text-fig. 52,

p. 80) and spatangoids (*Micraster* and *Collyrites*, Plate 3, fig. 15). In both of these the primordial ambulacral plates typically alternate with the primordial interambulacral plates to form the basicoronal row. In all other echinoids the primordial ambulacral plates are on the actinostome and form buccal plates both in the young and in the adult. Some very peculiar special modifications of this plan occur in aberrant cases in clypeastroids and spatangoids, as follows.

In *Arachnoides placenta* (Linné), Lovén (1874, Plate 51) showed that in the young, ambulacral and interambulacral plates alternate as usual. In the adult, the posterior odd interambulacral plate has been pushed dorsally out of the basicoronal ring, and the other primordial interambulacral plates in areas 1, 2, 3, 4, have disappeared by intracoronal resorption, so that as a result, the ten primordial ambulacral plates have come in contact and alone make up the basicoronal ring. They are in contact as they are typically in the buccal membrane around the mouth in regular Echini (*Bothriocidaris*), but the contact in *Arachnoides placenta* is a secondary contact not homologous with, though analogous to the original primitive contact. In specimens of *Arachnoides* that I have examined, both smaller and larger than those figured by Lovén, the primordial interambulacral plates are in place in the basicoronal row. It is probable, therefore, that Lovén's larger specimen as described was an exceptional individual variant, and not typical of the species.

In *Lovenia forbesi* Woods and Duncan, from the Miocene of Australia, the primordial interambulacral plates of areas 2, 3, 5, are in place in the basicoronal row, but the plates of 1 and 4 have been pushed dorsally so that the primordial ambulacrals Ib, IIa, and IVb, Va have come in contact instead of being separated by an interambulacral plate as usual.

In *Pourtalesia jeffreysi* Wyville Thomson, Lovén (1883, p. 13) shows the extraordinary condition that the primordial interambulacral plates 2, 3 join posteriorly the base of primordial interambulacral 5 and shut out the primordial ambulacrals I, V and II, IV from the peristomal row. In this highly aberrant type, therefore, the ventral margin of the corona is made up of the two primordial ambulacrals IIIa, b, and the sum of primordial interambulacrals 2, 3, and 5, as far as known a unique condition. Dr. Mortensen (1907, p. 73, Plate 17, fig. 21) shows in *Echinosigra* (*Pourtalesia*) *paradoxa* Mortensen, a most excessive lengthening and also narrowing of the basicoronal plates in areas I, 5, and V, making them, perhaps, the most peculiar plates of any echinoid, in a type that takes delight in breaking all rules of echinoid structure.

All the above are types of basicoronal plates in which there has been no encroachment by resorption of the ventral border of the corona. Where resorption has taken place to a greater or less extent, a different character of basicoronals prevails.

In the Palaeochinidae resorption has apparently cut away only the single primordial interambulacral plate and at the same time, as gathered from *Melonechinus* (Plate 56, fig. 8), some ambulacral plates have been transferred to the peristome. In these types we find two

plates at the ventral border of the interambulaerum and two in the ambulaerum (Maceoya, Plate 33, fig. 1; Lovenechinus, Plate 43, fig. 1; Oligoporus, Plate 50, fig. 8), or two in the interambulaerum and four in the ambulaerum (Melonechinus, Plate 56, fig. 2). Resorption may have cut away more than one row, probably three or more rows, when we have the condition in Arehaecoidaris (Plate 9, figs. 7, 8; Plate 10, fig. 10), where there are four plates in the interambulaerum and two in the ambulaerum in the basicoronal row.

Resorption may cut away an indeterminate number of plates, when we find the condition seen in most modern regular Echini, as Cidaris and Strongylocentrotus, with two interambulaeral and two ambulaeral plates in each area in the basicoronal row. This includes, I believe, the essential structure of the basicoronal row of all Echini. The proximal modifications of these plates by the development of the perignathic girdle are considered under that head (p. 190).

The enlargement of the peristomal aperture in Echini is attained by two methods: by the growth of the individual plates, which will enlarge the opening to any extent; or by cutting away the plates by resorption, which is a more obvious method of enlargement. The growth of the plates is, however, the more important factor. Even when resorption has not cut away any interambulaeral plates, as in Echinaraehnius, Spatangus, Arbacia (text-fig. 227, p. 193), and especially Phormosoma (text-fig. 43, p. 80), the size of the peristomal opening is many times larger than it was in the young individual.

IMBRICATION OF CORONAL PLATES.

In Echini, in many types, there is no imbrication in the coronal plates, the suture lines of the plates being so nearly perpendicular to the surface that the sides of a plate are as nearly parallel as possible in a curved test. The sides of a plate may be far from parallel where the plates are very thick, as in *Lovenechinus nobilis* (Plate 38, fig. 9), but still they are perpendicular to the surface and are therefore not imbricate.

Certain plates in Echini may present a strong angle on the suture line in a given direction, which Bather suggestively calls beveling. Beveling is applied as a term where the inclination is in a limited number of plates only. An excellent example is in the adradial suture of the Palaecechinidae. Here in all species of the family, as shown in *Lovenechinus septies* (Plate 45, fig. 5), the ambulaeral plates are inclined over the adjacent interambulaeral plates, so that a strong bevel results in the plates concerned. A similar bevel is seen in the petaloid area in some clypeastroids (Clypeaster), where the ambulaera are strongly inclined over the interambulaera on the adradial suture.

In *Clypeaster rosaceus* a curious combination of direction of beveling occurs. As stated, in the petaloid areas, the ambulaera bevel over the interambulaera as they do in the Palae-

echinidae. On the other hand, ventrally in Clypeaster, the interambulacra bevel over the ambulacra (text-fig. 234, p. 197) as in Pholidechinus or other types that have imbricate plates.

A succession of bevels, in a meridional or transverse series, as Bather (1909a, p. 64) says, produces imbrication properly so called. Imbrication is a character of many quite independent series in Echini, and while of genetic value in a limited series, cannot be used as a basis of close systematic connection in Echini as a whole, as I have shown (1896, p. 237).

As imbrication is confusing, especially in fossils where specimens are often viewed from the internal side, diagrammatic figures are given (text-figs. 32-39), illustrating the chief characters. Imbrication in Echini is curiously constant in its direction. Interambulacral plates in the corona always imbricate aborally in the vertical plane, so that the dorsal border of one plate is inclined over the ventral border of the next adjacent dorsal plate of its series (text-fig. 32). Interambulacral plates also always imbricate outwardly or adradially from the center, so that each plate from the center of the area laterally imbricates over its neighbor toward the ambulacral area and on the adradial suture imbricates over the ambulacral plates, as seen in *Lepidesthes wortheni* (Plate 67, fig. 8).

In the ambulacrum, on the contrary, the imbrication is always adoral, so that the ventral border of one plate inclines over the dorsal border of the next adjacent ventral plate, in the opposite direction from that of the interambulacral plates (text-fig. 38). Laterally there is little or no imbrication in ambulacral plates (*Lepidesthes*) except on the adradial suture, where the ambulacral plates dip under the adjacent interambulacrals instead of over them, as they do in the Palaeochinidae and in some clypeastroids, as above noted.

The imbrication of ambulacral and interambulacral plates, as described, occurs weakly in *Archaeocidaris*, *Lepidocidaris*, *Lepidechinus*, strongly in *Lepidocentrus* (Plate 20, fig. 8), *Hyattechinus* (Plate 22), *Pholidechinus* (Plate 28, fig. 2), *Perischodomus* (Plate 64, figs. 2, 3), *Lepidesthes* (Plates 66, 70), *Pholidocidaris* (Plate 73, fig. 4), and *Meekechinus* (Plate 76, fig. 1).

Imbrication also occurs in the modern thin-plated Echinothuriidae. This character has been considered a basis of connecting the Echinothuriidae with Palaeozoic types having imbricate plates, but so many characters are opposed to it, that this must be considered a case of parallelism. In modern forms, imbrication is not limited to the Echinothuriidae, but occurs also in the Centrechinidae. This character is well developed in *Astropyga pulvinata* (text-fig. 100, p. 109), where interambulacral plates imbricate dorsally and laterally, and the ambulacral ventrally. The plates are so thin that it is difficult to see the sutures of imbrication in cross section, but the imbrication is readily seen on the internal view of the test. The interambulacral plates imbricate over the ambulacrals, as they do also in echinothuriids, in *Centrechinus*, and in the Palaeozoic types with imbricate plates (as noted in the Palaeochinidae, the ambulacral plates are beveled over the interambulacrals, but imbrication proper does not occur in this family). Mr. Agassiz (1881, p. 71) notes the occurrence of imbrication in *Astropyga*, but

TEXT-FIGS. 32-39.— Method of imbrication of plates in Echini; the figures 32-38 are synthetic, based on studies of *Lepidesthes colletti* (Plates 69-71).

32. External view, interambulaeral plates are rounded in outline. Column 3 imbricates dorsally and laterally in two directions. Columns 1, 2, 4 imbricate dorsally and laterally in one direction and over ambulaerals. Ambulaeral plates imbricate ventrally, bevel under adjacent interambulaerals, but do not otherwise have lateral beveling.

33. Cross section of the same.

34. Internal view of the same. Interambulaeral plates are hexagonal in outline, angles of imbrication reversed from external view, ambulaeral plates with pores in the middle of plates, instead of near the interambulaerum as in external view.

35. Cross section of same.

36. Optical section of plates seen from exterior.

37. Optical section of plates seen from interior.

38. Showing in vertical section direction of imbrication of plates in the interambulaerum and ambulaerum.

39. *Eucidaris tribuloides* (Lamarck). Bahamas. R. T. J. Coll., 693. $\times 4$. Base of corona and peristome. On the peristome both ambulaeral and non-ambulaeral plates imbricate adorally, a condition not known in the corona of any echinoid.

says the plates of both areas imbricate in the same direction dorsally. I have studied imbrication in only one specimen, an *Astropyga pulvinata*; but in that one the ambulacra imbricate ventrally, interambulacra dorsally as described.

I believe the fact has been overlooked, but a weak imbrication occurs in *Centrechinus selosus*. It is not obvious in external view, but it is readily seen on viewing the interior of a test. The interambulacral plates imbricate dorsally as usual, and the ambulacral slightly ventrally; the interambulacra are inclined over the ambulacra on the adradial suture as usual in imbricate Echini, living or fossil. If a specimen of *Centrechinus* from alcohol is sectioned horizontally by cutting through the ambitus, it is found that there is much flexibility of the test. The same is seen in a dried specimen if it is first soaked in water. In *Chaetodiadema* the test is thin and highly flexible. It is very interesting that flexibility and imbrication are so characteristic of the Recent *Centrechinidae*, for many characters connect this family with the *Echinothuriidae*, as clearly shown by Messrs. A. Agassiz and Clark (1909). The rule of ventral imbrication for ambulacral and dorsal for interambulacral plates in the corona, is apparently without exception in the corona for all Echini where imbrication occurs. Certain exceptions according to the literature are said to exist. Worthen and Miller (1883) supposed that in *Lepidesthes* (= *Hybochinus*) *spectabilis* the interambulacral plates imbricate ventrally and the ambulacral dorsally. Their specimen was doubtless incorrectly oriented on account of the position of the teeth as discussed under the systematic description of that species, so that if I am correct it is no exception to the rule.

In my earlier paper (Jackson, 1896, pp. 223, 224) a serious error was made in regard to *Lepidocentrus mülleri* where the interambulacra were described as imbricating ventrally; this was wrong, since the specimen was inverted, as discussed under that species in this paper. Again, an error was made in describing *Pholidocidaris meeki* (1896, p. 211, Plate 9, fig. 54). The interambulacra and ambulacra were described as both imbricating adorally. The specimen (Plate 73, figs. 6, 7) is imperfectly preserved, and I can only plead guilty of an error of observation. I was also partly misled by the fact that Meek and Worthen's (1873, Plate 15, fig. 9a) figure of *Pholidocidaris irregularis*, the only good figure published, was inverted, a fact that was since ascertained. There is no proof at present that imbrication of coronal plates is ever other than dorsal in the interambulacra and ventral in the ambulacra in types of Echini with imbricate plates.

On the peristome, imbrication is adoral when it exists in both ambulacral and interambulacral plates, as in *Eucidaris* (text-fig. 39, also text-figs. 43, 46, 47, p. 80).

When imbricate specimens of fossil Echini are viewed from within (text-fig. 34), the structure appears very different from that as seen from without (text-fig. 32). This is shown well in *Perischodomus biserialis* (Plate 62, figs. 6, 7; Plate 64, figs. 2, 3). From the interior, the ambulacra appear to imbricate dorsally and laterally overlap the adjacent interambulacra;

also the ambulacra are wide internally instead of narrow, on account of their lateral beveling. The interambulacra appear to imbricate ventrally, as seen from the interior, and dip under the adjacent ambulacra. All this is reversed when the specimen is viewed from the exterior. This complication must be constantly borne in mind in a study of internal and external molds of fossils or confusion will ensue.

SPINES.

Having discussed the corona, a brief consideration may be given to spines as an obvious and salient feature of Echini. The name Echinodermata implies the character of spines. It is a misnomer, if the group as a whole is considered, for in the Pelmatozoa, spines are rarely developed, and in the holothurians are absent. Spines are, however, a feature of the Echini, and there is no known species which is without them. In the very young plates at the dorsal area of the test, spines are absent, not yet having developed. The nearest approach to this condition as a species character is seen in *Bothriocidaris pahleni* (Plate 1, fig. 3), which in the interambulacrum apparently has no spines in the adult. It is true that minute granules exist, which possibly bore spines, but such are not known. This species, however, has spines on the ambulacra and all other Echini have them on the interambulacra as well.

Spines are classed as primary, secondary, and miliary, and are attached to tubercles of corresponding size. In the Palaeozoic, primary spines are especially well developed in *Archaeocidaris*, where in each interambulacral plate there is a single large central perforate tubercle with an associated spine of variable but always relatively large size. In the youngest plates at the dorsal area, as shown in *Archaeocidaris rossica* (Plate 11, fig. 2), neither tubercles nor primary spines are developed, and when the tubercles develop, they are at first imperforate as seen in the younger dorsal plates in the figure cited. In *Eucidaris* (Plate 3, figs. 1, 2) a similar condition exists: the young tubercle is imperforate and the young spine is a thin hollowed plate, like an inverted saucer, its spine-like character developing in later growth. A young spine of a cidarid is short, broad, and distally rounded, and reminds one of the character of the spines of *Colobocentrotus*, except for the absence of marginal angles commonly developed in the spines of that type by mutual pressure.

Central primary spines are well developed in *Lepidocidaris* (Plate 16, figs. 1-3). Spines of larger size than associated spines and which may be fairly called primaries, are found irregularly distributed in *Lepidocentrus* (Plate 19, figs. 3-5), in *Hyaltechinus rarispinus* (Plate 23, fig. 6), and on the adambulacral columns in *Pholidocidaris* (Plate 73, fig. 3), and, judging from the tubercles, in part in *Perischocidaris* (Plate 67, fig. 2). In the several types considered, there are also small secondary spines clustered around the primaries and alone existent on the ambulacral plates (*Archaeocidaris*). Or secondary spines and tubercles may occur with pri-

maries on adambulacral columns and exist alone on other interambulacral columns and on the ambulacrum (*Pholidocidaris*, Plate 73, fig. 3; *Perischocidaris*, Baily, 1874, Plate 4). Secondary spines may exist without any primaries. Such is the condition in all the Palaeo-echinidae (Plate 52, figs. 10, 11), in *Lepidesthes* (Plate 70, fig. 4), and, judging from the small and uniform size of the tubercles, in *Lepidechinus* (Plate 63, fig. 3) such spines and tubercles may be fairly compared in size to those characteristic of *Clypeaster* and the usual type seen in clypeastroids. Such small spines as occur in *Bothriocidaris* (Plate 1, fig. 3) may probably be considered as primaries on account of the perforate tubercles and the small size of the whole animal. As far as known, spines are very uniform in character within the species in the Palaeozoic, cases of marked deviation, such as occur in some Cidaridae, being almost unknown in these older types. From this uniformity in the Palaeozoic, spines present very good species characters, which is fortunate, as they so often occur in a dissociated condition among fossils.

As discussed (p. 51), spines are typically internal, and the evidence indicates that they were internal, that is, covered by living epithelial tissue, in all Palaeozoic types excepting *Miocidaris* and possibly *Archaeocidaris*.

Stout, thick, and club-shaped spines are largely characteristic of the Cidaridae and a few other types. A specimen of *Strongylocentrotus dröbachiensis* in the Peabody Museum at Salem is interesting as showing thick club-shaped spines (Plate 6, figs. 11, 12), which are quite cidarid in appearance. These spines are numerous but rather local in distribution, not covering the whole specimen. The specimen is of normal size and appearance otherwise, and it appears to be merely a rare variation. This was the only such case seen in 33,000 specimens of this species examined, nor was such a structure seen in any other species of the family.

Tubercles as well as the spines with which they are associated may be divided into primary, secondary, and miliary. Primary tubercles may be perforate or imperforate. They are perforate in all Palaeozoic species where they occur; they are also perforate in the Cidaridae, Centrechinidae, and some of the Saleniidae, also in some spatangoids. Primary tubercles are imperforate in the remaining Centrechinoida, the Hololectypina, and many of the Spatangina. Secondary tubercles are imperforate in the Palaeozoic, whether they occur with primaries or alone, as in the Palaeo-echinidae. They are also imperforate in the Cidaroida and in *Acrosalenia*, but they are perforate in the Centrechinidae and certain clypeastroids and spatangoids (*Clypeaster*, *Metalia*, *Meoma*). Perforation of tubercles is evidently a character of primitive types and of some specialized types of clypeastroids and spatangoids.

Primary tubercles in a species occur with a definite distribution which is characteristic, as seen especially well in the Centrechinoida, a given number typically existing on a plate. It seems that the distance between tubercles which is maintained in a species is the real feature of their distribution. If, by chance, a plate is narrower than usual, as in *Tripneustes* (Plate 6, fig. 3), the tubercles are their usual distance apart, but there are fewer to a given plate;

or, if, by chance, a plate is wider than usual, as in the tetramerous *Arbacia lixula* figured by Verrill (1909), then again the tubercles are their usual distance apart, but there are more tubercles to a plate than is typical of the species (pp. 40, 47).

THE PERISTOME.

The peristome is closely associated with the corona, and is next considered. The peristome, which is the tissue lying between the mouth opening and the basicoronal plates, presents various characters in different groups of Echini, and these characters fall into six quite distinct types as described below.

The peristome in almost all Echini is more or less extensively covered with plates. There are in regular Echini ambulacral plates bearing tube-feet, either in one or in many rows. With these there may be in addition what I would call non-ambulacral plates, which do not bear tube-feet. Such non-ambulacral plates, where they occur in the Perischoechinoida and Cidaroida, occupy an interrarial position; or, where they occur in the Centrechinoida, they occupy also a radial position, being a more or less generally distributed series of plates (Toxopneustes, text-fig. 57). In spatangoids there are no ambulacral plates on the peristome, but non-ambulacral only. These are generally distributed over the area. I have adopted the term *non-ambulacral* for such plates because, though they may be interrarial only (Cidaridae), they may also have a general distribution, and they have no relation to the interambulacra of the corona.

The most ancient type of peristome known is that represented by *Bothriocidaris* (text-fig. 40) in which there are two continuous rows of ambulacral plates, a structurally primitive character. The first row around the mouth can fairly be considered the primordial ambulacral plates, and, as shown in *B. archaica* (Plate 1, fig. 1), this row follows Lovén's law of Ia, IIa, IIIb, IVa, Vb large and Ib, IIb, IIIa, IVb, Va small. Above the second row the corona proper begins with a row of five interambulacral and ten ambulacral plates. The line of separation between the peristome and the corona is not so strongly marked as in most types, but it is comparable to that of young *Phormosoma* (text-fig. 41), as pointed out by Mr. Agassiz (1904, p. 79). It is quite probable that the second row of peristomal plates in *Bothriocidaris* was derived by flowing down from the corona, but on the other hand there may have been two rows of peristomal plates formed before the development of the corona. In *Phormosoma* at a very young stage (Plate 3, fig. 9), as shown by Mortensen (1904, p. 54), there is only one row of peristomal plates, whereas a little later (text-fig. 41; Plate 3, fig. 10), as shown by A. Agassiz, there are two rows of peristomal plates almost exactly as in *Bothriocidaris*, as Mr. Agassiz (1904, p. 79) pointed out. The peristome of *Bothriocidaris* makes also very close approach to the character of the young in cidarids (Plate 2, figs. 1, 6) and young *Strongylocentrotus* (text-fig. 49), also other young Centrechinoida. It differs from these early stages principally in having

TEXT-FIGS. 40-54.— Characters of peristome and base of the corona in representative Echini.

40. *Bothriocidaris archaica* sp. nov. Ordovician, Russia. From Plate I, fig. 1. On the peristome two rows of ambulaeral plates.
41. *Phormosoma placenta* Wyville Thomson. Young. Diam. 9 mm. Adapted from A. Agassiz, 1904, Plate 43, fig. 3. On the peristome two rows of ambulaeral plates.
42. The same. Diam. 7 mm. Adapted from A. Agassiz, 1904, Plate 43, fig. 1. Peristomal plates with pores in a central peripodium.
43. The same, adult. Off Cape May to Cape Sable, 956 fath. Diam. 56 mm. R. T. J. Coll., 707. $\times 3$. On the peristome many rows of ambulaeral plates.
44. The same. Peristomal gills enlarged.
45. *Goniocidaris canaliculata* A. Agassiz. Young. Diam. 1.45 mm. From Plate 2, fig. 1. On the peristome one row of ambulaeral plates.
46. *Encidaris tribuloides* (Lamarek). Bahamas. Diam. 45 mm. R. T. J. Coll., 708. $\times 3$. On the peristome many rows of ambulaeral and in addition interradial non-ambulaeral plates (compare with young, Plate 2, fig. 6).
47. *Archaeocidaris wortheni* Hall. Lower Carboniferous. From Plate 9, fig. 6. Partially restored. On the peristome many rows of ambulaeral and in addition interradial non-ambulaeral plates.
48. *Melonchinus multiporus* (Norwood and Owen). Lower Carboniferous. Restored. From Plate 56, figs. 7, 8. On the peristome many rows of ambulaeral and in addition two rows of interradial non-ambulaeral plates; ambulaerals pass from two plates orally to many on the periphery of peristome in each area.
49. *Strongylocentrotus dröbachiensis* (O. F. Müller). Young. Diam. 1.2 mm. From Plate 3, fig. 11. On the peristome one row of ambulaeral plates.
50. The same. York Harbor, Maine. Adult. Diam. 40 mm. R. T. J. Coll., 709. $\times 3$. On the peristome one row of ambulaeral and scattered, small, non-ambulaeral plates.
51. *Dermatodiadema antillarum* A. Agassiz. West Indies, 955 fath. Diam. 9 mm. R. T. J. Coll., 670. $\times 8$. On the peristome one row of large ambulaeral plates.
52. *Echinarachnius parma* (Lamarek). Eastport, Maine. R. T. J. Coll., 747. $\times 2$. On the peristome no plates.
53. The same. $\times 6$. Peristome enlarged.
54. *Echinocardium flavescens* (Müller). Adapted from Lovén, 1874, Plate 3, fig. 34. On the peristome many non-ambulaeral plates only.

In text-figures 40, 41, 43, 45, 49, 52, and 54 the primordial interambulaeral plates are in place in the basicoronal row; in other figures they have been resorbed, with or without additional plates.

two rows of ambulaeral plates around the mouth instead of one row, a difference which is bridged in some types as shown in the development of *Phormosoma*.

A second type of peristome is that in which the area is plated with several rows of ambulaeral plates. The primordial ambulaeral plates surround the mouth as usual, and succeeding rows are composed of ten plates each, which are continuous, as are the primordial plates. Such a condition is seen in *Hyattechinus* (Plate 23, fig. 1), *Pholideechinus* (Plate 28, fig. 1), *Lepidesthes* (Plate 68, fig. 3), and *Palaeodiscus* (Plate 18, fig. 2). It is to be observed that in all these types the primordial interambulaeral plates were doubtless in place in the basicoronal row of the corona. The same character of only ambulaeral plates on the peristome is seen in Recent *Asthenosoma* (Lovén, 1892) and *Phormosoma* (text-fig. 43). It also occurs exceptionally in *Cidarids*, as shown by Mr. Agassiz (1904, p. 30, Plate 11, fig. 1). In the *Cidaridae*, however, the primordial interambulaeral plates are not retained at the base of the corona, but have been

resorbed. In all of these cases the ambulacral plates of the peristome are strongly imbricated adorally, and, as in *Bothriocidaris*, the pores are nearly or quite superposed dorso-ventrally.

A third type of peristome is where there are both ambulacral and non-ambulacral plates on the buccal membrane. The ten primordial ambulacral plates surround the mouth, at least as far as known, and are succeeded by rows of two or more plates in each ambulacral area aborally, separated by more or fewer interrarial non-ambulacral plates. Such a structure is seen in *Archaeocidaris* (text-fig. 47) and *Melonechinus* (text-fig. 48) in the Palaeozoic. In *Archaeocidaris* there are two vertical columns of ambulacral plates and many columns of scale-like non-ambulacral plates increasing in number aborally to the margin of the actinostome, where they have a greater number of plates than exist in the basicoronal row of the interambulacrum. Both ambulacral and non-ambulacral plates on the peristome imbricate strongly adorally. This structure has been made out more or less fully in four species of *Archaeocidaris*, namely, *A. wortheni* (Plate 9, fig. 6), *A. rossica* (Plate 11, fig. 1), *A. agassizi* (Plate 13, fig. 3), and *A. urii* (Plate 15, fig. 1). In *Melonechinus* (text-fig. 48; Plate 56, figs. 7, 8) there are two plates in each ambulacral area around the mouth, but passing outward, they increase to many plates in each row before reaching the corona. There are but three non-ambulacral plates in each interrarial area on the buccal membrane. This is based on a single specimen, but it is probable that a similar structure may exist in other members of the family of the Palaeoecchinidae. Ambulacral and non-ambulacral plates of this type on the peristome are a character of the Cidaridae alone among Recent Echini. The plates imbricate strongly adorally in both areas (text-fig. 39, p. 75), as in *Archaeocidaris*, emphasizing the primitive character of this structure. In the peristome of *Eucidaris* (text-fig. 46; Plate 2, fig. 6) there are two plates in each row in each ambulacrum. In the interrarial areas there may be one plate in each row, or passing outward, this may increase to two plates in a row; or in *Phyllacanthus* (Plate 2, fig. 18), as shown by A. Agassiz and Clark (1907a), there may be as many as five plates in a row in each area interradially on the border of the actinostome. While in adult *Eucidaris tribuloides* there are many rows of very low scale-like ambulacral plates on the peristome (text-fig. 46), in a young specimen of 5 mm. diameter (Plate 2, fig. 6) there are only four rows, and the plates are high, hexagonal in outline, resembling the similar plates in *Bothriocidaris*.

Mr. Agassiz, in the Revision of the Echini (1874, p. 646), compared the actinostome of *Cidaris* to the whole ambulacral and interambulacral system of Palaeozoic Echini. As he said, "Obliterate the two rows of coronal plates [of *Cidaris*] and we have a spherical urchin composed of a series of plates corresponding in every respect to the hypothetical Palaeoecchinus. It consists, namely, only of an abactinal system, . . . of an ambulacral and interambulacral system, composed of hexagonal and pentagonal plates, perfectly flexible, and of an oral opening through which we find teeth projecting." Mr. Agassiz (1892, p. 72) again said in his monograph on *Calamocrinus diomedae*, "The structure of the test of *Bothriocidaris* is represented

by the buccal system of *Cidaris*. One range of interambulacral plates extending from the apex to the actinostome intercalated between rows of ambulacra with two pairs of pores each."

There are several objections to comparing the test of Palaeozoic Echini with the peristome of *Cidaris*. Representative genera of Palaeozoic types have a peristome and ventral border of the corona directly comparable to the same parts in living Echini. The family of the Palaeoechinidae (*Palaeoechinus*, *Melonechinus*, etc.) which have hexagonal plates, do not have flexible tests. Of course specimens may be crushed and plates displaced in fossilization, but they cannot be described as flexible. Those Palaeozoic genera which do have flexible tests have imbricate plates, but the imbrication in the interambulacra of the corona is always dorsal (text-fig. 32, p. 75), as in the Echinothuriidae, not ventral as is the imbrication of all the plates on the peristome of *Cidaris* (text-fig. 39, p. 75). While cidarids usually have a single column of plates in each interradial area on the actinostome, this is not a constant number, and on the aboral portion there may be two plates in a row, or as many as four or five, as in the *Phyllacanthus* noted.

The above three types of peristomes cover all the known cases in Palaeozoic Echini, but there are yet three other types in post-Palaeozoic Echini which have interesting relations to the Palaeozoic forms. A fourth type is seen in the Centrechinoida (excluding the Echinothuriidae), in which we have typically (*Strongylocentrotus*, text-fig. 50) only ten ambulacral plates around the mouth. These plates have each two pores which are superposed dorso-ventrally, as in *Bothriocidaris*. In the young (text-fig. 49), as shown by Lovén, these plates lie close under the corona, as do the similar plates in young cidarids and in adult *Bothriocidaris* (only in this last type there are two rows of plates). In the adult (text-fig. 50) the primordial ambulacral plates are usually far removed from the base of the corona, and the surrounding membrane is usually more or less covered by solid, sealy, isolated, or granular plates which apparently cannot be distinguished as ambulacral or interambulacral, but seem to have developed independently in place. On the margin of the peristome in the Centrechinoida are found ten peristomal gills. These may be very small, as in *Phormosoma* (text-fig. 44), or may be large and frondescent, as in *Strongylocentrotus* (text-figs. 55, 56).

While, as a rule, there are ten primordial ambulacral plates typically in all Echini, as far

TEXT-FIGS. 55, 56.

55. *Strongylocentrotus dröbachiensis* (O. F. Müller). York Harbor, Maine. $\times 5$. Peristomal gills in place, expanded.
56. The same. Profile view of a gill.

as known, Dr. Mortensen (1904, p. 78) gives a remarkable exception, for he says that in *Pleurechinus döderleini* Mortensen there are only five buccal ambulacral plates, a "unique feature." This may fairly be considered an exceptional departure from the ten-plate system rather than instituting a distinct type. In the Centrechinoida the non-ambulacral buccal plates are usually small, thin, and scale-like, often widely scattered, and may be mere granules, or they may be quite absent, as in *Echinus magellanicus* and some of the Temnopleuridae. They may, however, be relatively thick and solid and form a pavement-like plating of the whole

TEXT-FIG. 57.—*Toxopneustes variegatus* (Lamarck). Tampa Bay, Florida, diam. 70 mm. R. T. J. Coll., 784. $\times 4$. Peristome with ten ambulacral and many non-ambulacral plates.

area, as in *Toxopneustes variegatus* (text-fig. 57). Here the primordial ambulacral plates fall in sets of twos in the radial areas with a rather wide interspace between the sets. The pores of these plates are superposed dorso-ventrally as usual in peristomal plates.

In *Dermatodiadema* (text-fig. 51), as shown by Mr. Agassiz (1883, p. 26, Plate 9, fig. 5; 1904, p. 61, Plate 25), the primordial ambulacral plates are extraordinarily large and fill a considerable part of the buccal membrane, a retention of a primitive character.

A fifth type of peristome is seen in clypeastroids (*Echinarachnius*, text-figs. 52, 53), in which the primordial ambulacral plates no longer exist as part of the buccal system, but have become transferred to the basicoronal row of the corona, where they are typically retained throughout life, alternating with the primordial interambulacral plates. The buccal membrane proper in *Echinarachnius* and, as far as I have been able to ascertain, in other genera of this suborder, is leathery without plates.

Still a sixth type of peristome is seen in spatangoids (*Echinocardium*, text-fig. 54). In these the primordial ambulacral plates are in the basicoronal row of the corona, as in clypeastroids. The buccal membrane, however, is covered with numerous thin, scaly plates which, as in the *Centrechinoidea*, cannot apparently be considered as ambulacral or interambulacral, but as plates which developed in place and independently of the corona.

In brief the six types of peristomes are:—

1. Two rows of continuous ambulacral plates,— the primordial row and one in addition (*Bothriocidaris*, text-fig. 40).
2. Many rows of continuous ambulacral plates (*Hyattechinus*, Plate 23, fig. 1, *Phorimosoma*, text-fig. 43).
3. Many rows of ambulacral with intercalated interrarial non-ambulacral plates (*Eucidaris*, text-fig. 46; *Archaeocidaris*, text-fig. 47; *Melonechinus*, text-fig. 48).
4. One row of continuous primordial ambulacral plates around the mouth, and usually, in addition, solid, scaly, isolated, or granular non-ambulacral plates¹ (*Dermatodiadema*, text-fig. 51; *Centrechinus*, *Salenia*, *Strongylocentrotus*, text-fig. 50; *Toxopneustes*, text-fig. 57).
5. No primordial ambulacral plates, as they are in the corona; peristome leathery with no ambulacral or other plates (*Echinarachnius*, text-fig. 52).
6. No primordial ambulacral plates, as they are in the corona; area of peristome with scaly plates which are not referable to ambulacra or interambulacra (*Echinocardium*, text-fig. 54).

The origin of the plates of the peristome is a matter of much interest. Without question the primordial ambulacral plates, when they exist on the peristome (as they apparently do in all Echini excepting the *Exocycloidea*, where they appear typically as basicoronal plates), originate in that area and entirely independently of the corona. In *Bothriocidaris* it is possible that the second row of ambulacral plates, like the primordial ambulacral plates, originated on the peristome and independently of the corona, but more probably they were derived by flowing down from the corona.

When ambulacral plates other than primordial ambulacral plates exist on the peristome,

¹ In some of the *Temnopleuridae* (A. Agassiz, 1872, p. 286; Mortensen, 1904, p. 80) and *Echinidae* (Döderlein, 1906, p. 226) the non-ambulacral plates are absent.

it seems, as shown by Lovén (1892, p. 18) and A. Agassiz (1904, pp. 31, 96, 97, *et al.*), that they are derived from the corona. As Lovén describes it, the ambulacrals flow downward between the interambulacrals and pass as if discharged through the outlet of a river on to the buccal membrane. Such is the condition in the Palaeozoic Hyattechinus (Plate 23, fig. 1), Pholidechinus (Plate 28, fig. 1), Melonechinus (Plate 56, fig. 8), modern Eucidaris (text-fig. 46) and Phormosoma (text-fig. 43).

Lovén (1892, pp. 22, 31) also assumed that the interradiial plates on the peristome of Cidaris and the granules and small non-ambulacral plates of "Ectobranchiates" are formed by the disintegration and remodeling of coronal into buccal plates. He speaks of coronal plates as disintegrating and the calcareous substance being redeposited as buccal plates. This seems a quite untenable view. If the plates are dissolved, that should be the end of them, and we cannot assume that buccal plates are derived from the resulting lime any more than the thickening of teeth or any part of the test. I believe no one has shown the interambulacral plates separating from the corona in Echini and passing on to the peristome, there to be represented by actually transferred larger or smaller plates. Outside of the transferred ambulacral plates, as seen in Cidaris and similar types, it seems that all plates of the peristome originated in that area and cannot be considered as derived from the corona. In spatangoids the peristome is usually densely plated, yet no resorption of the base of the corona has occurred, and the primordial ambulacral and interambulacral plates are in place in the basicoronal row, therefore no transfer of coronal plates can have taken place.

OCULAR AND GENITAL PLATES.

The range of characters presented by the ocular and genital plates is most interesting. Their mutual relations are discussed here, and in the next section certain considerations of the genital plates by themselves are taken up. Cases of marked aberration occur in some spatangoids as Collyrites, and especially Pourtalesia; these I have not studied, and they are eliminated from the discussion. The characters of oculars and genitals are typical of the several groups of Echini, and the later forms present striking relations to Palaeozoic genera. An ocular plate in Echini overlies an ambulacrum wholly and the two adjacent interambulacra in part on either side. Immediately on the ventral borders of the oculars all coronal plates originate. It seems that at this point the tissues exist which give rise to new plates. As earlier discussed (p. 62), the corona may be considered as made up of five areas, each of which is directly connected with one of the ocular plates, the areas being each an ambulacrum and two half-interambulacra (text-figs. 217, 218). The five oculars are always present barring the excepted Pourtalesia. The genitals overlie the interambulacra in part, but not the lateral borders of the same, and never reach the ambulacra. In some cases the genitals may not

reach the interambulacra. Five genitals are typically present, but the posterior genital may be wanting (spatangoids) or one absent as an aberrant variation (Arbacia, Plate 4, figs. 11, 12; or Eucidaris, text-fig. 185, p. 167).

The apical disc is large relatively to the diameter of the test in young Echini (Plate 2, fig. 3); it is also relatively large in the adult primitive Bothriocidaris. With growth to the adult the apical disc in Echini loses its preponderance but is still relatively large in the Cidaridae, in Tiarechinus, in the Aspidodiadematidae and Saleniidae. In the Devonian and Carboniferous Echini and in the Centrechinoida, other than those mentioned, the apical disc is relatively small. In the Echinometridae which in other respects are amongst the most specialized of regular Echini the apical disc is very small as it is also in the Exocycloida. As far as observed commonly the apical disc in relation to the test as a whole grows with a progressively decreasing ratio, a fact that can be verified from the figures shown here as text-figs. 63, 67, 128, 129a, 135, 137. Very large individuals do not necessarily have larger periprocts than smaller individuals of the same species (text-figs. 94-95, 151-153). In general a proportionately large apical disc is a youthful and primitive character, a small one is a progressive character.

In the ancient Bothriocidaris the oculars are exceptionally large, relatively to the size of the animal; on the other hand, the genitals are exceptionally small, relatively the smallest of all known Echini. There has been much confusion in regard to the genital plates of this type, but, having enjoyed the privilege of studying perhaps the most perfect specimen known, which is in the Berlin Museum, I have reached the following conclusions.

In *Bothriocidaris archaica* (Plate 1, fig. 2) the oculars are very large; they are in contact with the periproct dorsally, and meet in a continuous ring covering entirely both the ambulacral and interambulacral areas. What I consider the genitals are five small plates lying in the dorsal angles of the oculars and extending into the periproct. The relative position of the oculars and genitals in this most ancient and, I believe, primitive echinoid is closely comparable to that of the same plates in the larval Echinus (Plate 3, fig. 5).

In *Bothriocidaris pahleni* (Plate 1, fig. 6) as shown by Schmidt (1874) the oculars are also large; two of the genitals extend down between the oculars and come in contact with the dorsal border of the interambulacra (one is absent), but two lie completely dorsal to the oculars as do all the genitals in *B. archaica*. In this character, therefore, it is intermediate between that species and the next. In *Bothriocidaris globulus* (Plate 1, fig. 9), as Schmidt (1874) showed, the oculars are large, as in the two other species, but the genitals all extend down between the oculars and reach the dorsal border of the interambulacra in their several areas as in all later Echini. The position of genitals dorsal to the oculars is, of course, a common condition in living Echini, the main peculiarities in *Bothriocidaris* being the relatively small size of the genitals, and the fact that they may be excluded from contact with the interambulacra in *B. archaica*, a unique specific character.

It is interesting to note that in a striking regressive variation in *Arbacia punctulata* (Plate 4, fig. 11), interambulacrum 4 drops out to a single column of plates in the last four rows built, and dorsally abuts against two oculars, the single column and ocular contact being exactly as in *Bothriocidaris archaica*. A similar condition is seen in *Tripneustes* (Plate 6, fig. 4), *Strongylocentrotus* (Plate 6, figs. 7, 8), and *Eucidaris* (text-fig. 185, p. 167). In a unique specimen of *Strongylocentrotus dröbachiensis* (Plate 5, fig. 16) genital 1 lies wholly dorsal to the oculars as do all the genitals in *Bothriocidaris archaica* (p. 42).

No pores have been observed in genital plates in *Bothriocidaris*. It is possible they did not have genital pores, as such are wanting in the young of Recent Echini; more likely they were present, but do not show in external view, and in this they may fairly be compared with *Salenia pattersoni* (Plate 4, fig. 1) where no pores were seen from the exterior, though they are perfectly visible on the interior of the test (Plate 4, fig. 2). Also no pores have been observed in ocular plates of *Bothriocidaris*, though in ocular III (Plate 1, fig. 2) there is a peculiar arcuate impression that may function as a pore.

Neumayr (1881) and Mortensen (1911) consider as genitals in *Bothriocidaris* the plates lying ventral to the oculars, which I consider as the dorsal plates of the interambulacra. If they are right, then the genitals would be ventral to the oculars, a position opposed to that in all known Echini; also the interambulacra would be separated from contact with the oculars, whereas they are in contact with the oculars in all known Echini.

Bather (1902), speaking of the periproct of *Bothriocidaris*, says that the area is filled with minute plates, none of which can safely be selected as the homologues of the genitals of later forms. If it depended on *Bothriocidaris archaica* alone, it might be doubtful, but when we see in *B. pahleni* in part, and in *B. globulus* in full, the five plates extending down between the oculars so as to come in contact with and cap the interambulacra as genitals do in all later types, it is reasonable to consider these plates as genitals.

Mr. Agassiz (1892, p. 72) says of *Bothriocidaris*, "... we find five radials and five inter-radials forming a single ring round the anal system. At the [dorsal] angles of the radial plates five small anal plates are situated." Again Mr. Agassiz (1904, pp. 79, 80) says, "The genital ring of *Bothriocidaris* as well as of the *Palaechinidae* is much like that of the recent echinids, only in the former the ocular plates are far larger than the small plates corresponding to the genitals. The anal system of *Bothriocidaris globulus* Eichw. as figured by Jaekel¹ shows, as in the very young *Cidaridae*, five anal plates in the angles of the ocular plates...." Mr. Agassiz evidently considered as genitals those plates ventral to the oculars as did Neumayr and Mortensen, and those dorsal to the oculars as anals; whereas I consider those ventral to the oculars as the last formed plates of the interambulacra, and the five interrarial plates dorsal to the oculars

¹ The specimen mentioned is the *Bothriocidaris archaica* sp. nov., Plate 1, figs. 1, 2, of this memoir.

as genitals. By a slip of the pen Mr. Agassiz in the paragraph quoted compares the five plates in the dorsal angles of the oculars of *Bothriocidaritis* to five anal plates in young cidarids. The five plates in *Bothriocidaritis* (Plate 1, fig. 2) are interradian in position and lie between the oculars, whereas the five somewhat similar plates in young cidarids (text-fig. 61, *Porocidaritis eobosi* A. Agassiz, 1904, Plate 13, fig. 5), are radial in position and lie between the genitals, for the genitals alone reach the periproct, the oculars at this stage in cidarids being exsert.

Genital and ocular plates are rare in Palaeozoic types, yet excepting the Echinocystoida I am able to show them in all families other than the Archaeocidaridae and in most genera. After *Bothriocidaritis* just considered, the leading character in the Palaeozoic is for all the oculars to reach the periproct, and to cover the ambulacra and in part the interambulacra on either side. Also the genitals reach the periproct, are larger than the oculars, and cover the interambulacra in part, but not wholly, because the lateral borders of the interambulacra abut against the next adjacent ocular on either side. This character is shown in *Palaeochinus* (Plate 31, fig. 4), *Maccoya* (Plate 34, fig. 6), *Lovenechinus* (Plate 42, fig. 6), *Melonechinus* (Plate 56, fig. 6), *Hyattechinus* (Plate 25, fig. 5), *Lepidechinus* (Plate 63, fig. 7), and others.

In one specimen of *Lovenechinus missouriensis* (Plate 41, fig. 2) in areas D and F, the oculars are exsert, but in six other specimens of the species, with all oculars in place, all the oculars reach the periproct. In *Lovenechinus lacazei* (text-fig. 243, which I owe to the kindness of Dr. Bather), all the oculars are exsert. In *Maccoya intermedia* (Plate 33, fig. 11) one ocular is exsert, four insert; and in Plate 33, fig. 12, all the oculars are exsert. In *Lepidechinus tessellatus* sp. nov. (Plate 63, figs. 7, 8) the oculars are all exsert as far as preserved, and the same is true of *Meekechinus elegans* (Plate 76, fig. 5). These are the only cases of exsert oculars observed in Palaeozoic Echini, and may be fairly considered as forerunners of the dominant character seen in Mesozoic and many Recent regular Echini.

In the Palaeozoic the oculars of *Lepidesthes formosa* (Plate 68, fig. 5) have two pores each. Oculars in *Lovenechinus missouriensis* (Plate 42, fig. 6) show a single pore of small size close to the ventral border of the plates, and the same is seen in *Lepidechinus tessellatus* (Plate 63, figs. 7, 8). These last two cases are views of the interior, not the exterior of the plates, and it is possible that the pores did not reach the surface, or did not reach it so as to be seen in external view, as is the usual case in *Salenia*. In all other Palaeozoic Echini seen, the ocular plates are imperforate. Baily (1865b) figured two pores in *Palaeochinus elegans*. His original specimen is shown in Plate 29, figs. 3, 6; Plate 31, fig. 4. The specimen does not have any pores in the oculars and Baily's observation was an error, which has proved unfortunate as his figure of the apical disc has been extensively copied. The characters of pores in the genitals and other special features of these plates are considered in the next section. In post-Palaeozoic Echini ocular plates have one pore not always visible externally (*Salenia*, *Arbaeia*) and very rarely a second pore may exist as a variant. I have seen only two or three such.

Genital plates may be divided by secondary sutures as later discussed, but oculars are very rarely divided. A case, however, is shown in text-fig. 193, p. 169, in which dividing sutures develop in ocular plates, as also seen in Plate 6, fig. 6.

Having seen the characters of ocular and genital plates in their mutual relation in the Palaeozoic, it is of much interest to compare those of later times. Little attention has been directed to these plates, but a close study reveals characters of importance to general morphology, to the evolution of the group, to the relation of the species in the genus and related genera, and to geographical distribution. Ocular plates present an excellent systematic character which has been largely overlooked. Osborn (1901) in a brief but very suggestive paper called attention to the variations of ocular plates in *Arbacia* and compared these variations with the characters of Palaeozoic types.

Early in my studies of these plates it was seen that they had an important bearing, and observations were made on all available specimens of regular Echini, Mesozoic and Recent. In the fossils this is not always easy, as for purposes of study, all five oculars and genitals must be observed, and they are frequently lost in fossils. I have succeeded, however, in making observations on something over 50,000 regular Recent and Mesozoic specimens representing 133 species. The results are presented in tabular form and the more interesting cases are described. In the tables in certain species, developing series are given as well as developed series, notably in *Strongylocentrotus dröbachiensis*; in other species the specimens listed were not all adults, but were all large enough so that they were believed to be fully developed, being for the most part nearly or quite half grown. Of the species tabulated all specimens seen are included excepting young specimens, those without locality, where this was a feature of importance, tetramerous or hexamerous individuals, and a very few distorted specimens that could not properly be included. The reason for making so many observations was that while the character of a species is usually gathered correctly from five or ten specimens, the variations seen in a large number present interesting data for comparative study.

One may expect to find the common variants in from 25 to 100 specimens, and 500 to 1,000 may reasonably be expected to yield all the variants at all likely to occur. For an exhaustive study of variation, however, many thousand specimens of a species may be profitably studied.

In Mesozoic regular Echini the dominant character is for all the oculars to be exsert, or excluded from the periproct. In the Recent regular Echini the young also have all the oculars exsert.¹ In the adult all the oculars may be exsert or one or more may be insert. While the exsert character of the young is like the Mesozoic, the becoming insert in development is the taking on of a character which in this respect is directly comparable to the dominant character of the Palaeozoic.

¹ By young is meant specimens of from 2 to 5 or more millimeters in diameter. At an extremely early stage, at least as shown in Echinus, Plate 3, fig. 5, all the oculars reach the periproct. A general conception of the characters of this stage is represented schematically in Plate 3, fig. 7.

Most species have a definite character as to whether all plates are exsert or how many become insert, but in some species there is much variation, and in most species where many observations have been made there is some variation. The relative frequency of typical variation in selected species is shown diagrammatically in text-fig. 176, p. 153. In the tables, pp. 100, 101, 142, 143, 154-164, are given in detail the relations of the ocular plates to the periproct as observed in 50,000 specimens, including the leading genera and species of post-Palaeozoic regular Echini belonging to the orders Cidaroida and Centrechinoida.

As becoming insert is a progressive character with development, species in a genus that have the greatest number of ocular plates insert may be considered in this respect more evolved than other species which have a less number (Arbacia, Echinometra). Also, as a matter of variation, individuals that have fewer oculars insert than is characteristic of the species may be considered arrested variants, and those that have more plates insert than is typical may be considered progressive variants. Such variants can frequently be compared directly with related species or genera where the fewer or greater number of oculars insert is a typical specific character (Centrechinus). Specimens of a given species from different localities present often quite striking differences as regards the number of plates which are insert, those from one locality having typically fewer oculars insert than those from a different locality. Such variation with locality may well be considered as indicating incipient species, as, where there is a difference, specimens from one locality must be more progressive or less progressive than those from another (*Cidaris affinis*, p. 100, *Tripneustes esculentus*, p. 161, *Strongylocentrotus dröbachiensis*, p. 143, and *Echinometra lucunter*, p. 163).

The number of oculars insert has been spoken of by previous writers as if it were a concurrent of age, and the largest specimens had the most oculars insert. My observations are directly opposed to this view. All the evidence goes to show that the full number of oculars that are to become insert are developed early in the life of the individual, and apparently later no change in this respect takes place. A series of specimens half the mature size or larger may in most species be safely accepted as showing the mature characters as regards oculars. This is on the basis of observations on 11,500 specimens of *Strongylocentrotus dröbachiensis*, all from one locality, Dumpling Islands, the specimens varying from very young to adult, and all measured and tabulated as later described. With few exceptions it was found that the larger individuals in a species are typical as regards ocular plates, and that variations, both arrested and progressive, are more frequent in smaller individuals, often half grown as regards size.

In many cases it has been found that my observations of the typical number of oculars insert do not agree with the published descriptions of the species. This is probably due to the fact that variation was not considered, and descriptions were drawn from a specimen or specimens that happened to be variants. It is not enough to consider how many ocular plates become insert, but which ones is an important matter. In this there is a certain difference

in the two orders of modern regular Echini, and the sequence of incoming in these orders will now be taken up.

In the Cidaroida, ocular plates are all exsert in the young, and in adults may be all exsert, or part or all may be insert as a species character (text-figs. 58-74). When oculars become insert, typically V comes in first. It is possible that in some species ocular I may come in before V as both systems occur in the Centrechinoida. After V, ocular I comes in, marking a bilateral symmetry, as these are the plates of the bivium. After the bivium, ocular IV next becomes insert. Up to this point the sequence is as in the Centrechinoida, and V, I, IV insert is a common character in the Cidaroida. Ocular II may come in next (*Eucidaris tribuloides*) when we have the sequence V, I, IV, II insert, the bivium and posterior pair of the trivium, indicating a bilateral symmetry and being the character that prevails strongly in the Centrechinoida and Spatangina. Or, on the other hand, ocular III may typically come in after IV (*Cidaris affinis*), when we have the sequence V, I, IV, III. This is the sequence described by Clark (1907, p. 193) in several genera of the family. It is rare in the Centrechinoida and unknown in the Spatangina. If ocular II comes in first, then III is the last to enter the periproct, or if III comes in first, then II is the last to enter the periproct. The sequence as stated in the Cidaroida is adhered to in 99.31% of the 1,459 specimens observed. There were only ten aberrants, or 0.69%. These aberrants all occurred in two species, *Cidaris affinis* and *Eucidaris tribuloides* as there described, and all but one of these may be considered cases of incomplete I, V, IV, III (pp. 96, 97, 99.)

In the Centrechinoida the ocular plates, barring slight variation, come in or reach the periproct in a perfectly definite order. The sequence of incoming is I, V, or V, I, then IV, II, III (text-figs. 118-127). It is to be noticed that this order is the bivium first, then the posterior plates of the trivium, and finally, if at all, the odd anterior ocular. This emphasizes the orientation of Lovén in comparison with the bilateral Echini, and points out a bilateral symmetry in the regular Echini not before suspected. The bilateral symmetry is shown by the fact that ocular plates come in, or become insert, in definite sequence on each side of the axis through III, 5, which is the elongate axis of bilateral types, as in spatangoids. Thus the posterior plates (the bivium) in the Centrechinoida are the first two to become insert, as in the spatangoid *Cassidulus* (text-fig. 172, p. 149), next the left anterior ocular comes in, as in *Micraster* (text-fig. 174), then the right anterior ocular follows, as in *Ananchytes* (text-fig. 175, p. 149). There is therefore a direct relation between the order of incoming of oculars in regular Echini and that which obtains in the Exocycloida.

The order of sequence in which the bivium comes in emphasizes family characters. The order I, V is characteristic of the Hemicidaridae, Centrechinidae, Saleniidae, Stomopneustidae, Temnopleuridae, Echinidae, and Strongylocentrotidae (text-figs. 128-134). On the other hand, the order V, I is characteristic of the Arbaciidae and the Echinometridae (the latter as here restricted, see tables pp. 158, 163), text-figs. 111-114, 158-161.

To show the regularity of sequence of incoming of ocular plates in the Centrechinoida, it may be put briefly as follows. In the total 48,541 specimens of this order examined and tabulated, 6,235 have all the oculars exsert. In 3,300 specimens there is one ocular insert, and of these in 3,279 cases, it is either ocular I or V, that is, 99.36% are correct by rule. Only 21 specimens are aberrant, and these have either ocular IV (text-fig. 140, p. 134) or II insert, or in three instances ocular III alone is insert. In 35,184 specimens, two oculars are insert, and of these it is I and V, the bivium, in 34,881, or 99.14%, are correct by rule. In all of the 303 exceptions, one of the two plates insert is either I or V. In 97 of these, oculars I, IV are insert, and in 76% of them genitals 4, 5 are fused, as in text-fig. 144, p. 134, mechanically excluding ocular V from the periproct. These may therefore be properly considered cases of an incomplete I, V, IV insert. In 56 of the exceptions, oculars I, II are insert (text-fig. 141, p. 134). This character was found only in the Echinidae or in the nearly allied Strongylocentrotidae and is a species character in *Gymnechinus pulchellus* and *robillardii* (text-figs. 177-179, p. 165). In 82 of the exceptions, oculars V, IV are insert (text-fig. 142, p. 134). This is especially common in the Arbaciidae, and in no case was an ocular excluded by the fusion of genitals. In 63 cases, oculars V, II are insert. This combination was seen in the Saleniidae, Echinidae, Strongylocentrotidae, and Echinometridae, and in all of the cases in the families Echinidae and Strongylocentrotidae genitals 5, 1 were fused, excluding ocular I (text-fig. 146, p. 134), so that this combination may properly be considered an incomplete I, V, II, which character is common in those families. One specimen has oculars I, III, and four have V, III insert, which are sporadic variants.

In 2,917 specimens there are three oculars insert. Of these in 2,584, or 88.58%, it is oculars I, V, IV, that is, the bivium and left posterior plate of the trivium. Of the 333 exceptions, in 300 cases the order is I, V, II insert (text-fig. 145, p. 134); that is, the right posterior plate of the trivium is insert instead of the left posterior, as usual. These may be considered as right-handed specimens. This combination was not seen in the order Cidaroida, or in the families Centrechinidae and Arbaciidae where three plates are frequently insert, but it is a feature of the families Saleniidae, Stomopneustidae, Echinidae, and Strongylocentrotidae. It is especially frequent in *Sphaerechinus granularis* and *Tripneustes esculentus*. When three plates are insert in the Centrechinoida, it is typically the bivium and usually the left, but occasionally the right, posterior plate of the trivium, and this rule is adhered to in 98.87% of the 2,917 cases observed. There were only 33 exceptions to the above. In 17 of these, oculars V, IV, II are insert, but ocular I was always excluded by the fusion of genitals 5, 1 (text-figs. 148, p. 134 and 196, p. 169), so that this combination may reasonably be considered an incomplete I, V, IV, II insert. In one case oculars I, IV, II are insert (text-fig. 147, p. 134), with genitals 4, 5 fused, excluding ocular V, evidently also an incomplete I, V, IV, II insert. In addition, four of the cases are I, V, III insert, a sporadic variant, and eleven are cases of V, IV, III insert.

This last is the dominant character of *Strongylocentrotus gibbosus* (text-fig. 156, p. 145), in which species a commensal crab profoundly modifies the apical disc.

In 387 specimens, four oculars reach the periproct, and of these in 340, which is 87.86 % of the cases, the order is I, V, IV, II, the bivium and posterior pair of the trivium (text-fig. 126, p. 124). Of the 47 exceptions, the order in all is I, V, IV, III insert (text-fig. 149), and this order is common as a character in the Cidaroida (text-fig. 69, p. 98). It is interesting to note that 32 of the 47 cases of this aberration occur in *Centrechinus*, which genus is relatively near the base of its order, and therefore nearer to the Cidaroida. When, therefore, four oculars are insert in the Centrechinoida in all, or 100%, the arrangement is that characteristic of the order, or is reversionary to the character frequent in the Cidaroida. In 518 specimens all the oculars are insert.

Of the total 48,541 specimens of Centrechinoida observed and tabulated, when oculars become insert, they come in in the order of sequence I, V, or V, I, IV, II, III in 98.55%, and they are out of order, or aberrant for the Centrechinoida in 704 cases, or 1.45%.

Of the above considered aberrants as there stated, certain combinations of ocular plate arrangement can be definitely accounted for, the I, V, II insert (300 specimens) as right-handed individuals (text-fig. 145, p. 134); the I, IV (97 specimens) are incomplete I, V, IV by the usual exclusion of ocular V, due to the fusion of genitals 4, 5 (text-fig. 144, p. 134); the V, II (63 specimens) text-fig. 146, as incomplete I, V, II, due to the usual fusion of genitals 5, 1, excluding ocular I; the V, IV, II (17 specimens), text-figs. 148, p. 134 and 196, p. 169, may be considered as incomplete I, V, IV, II, due to the exclusion of ocular I by the fusion of genitals 5, 1; the I, IV, II (1 specimen), text-fig. 147, (p. 134) is similarly accounted for by the exclusion of ocular V. Finally, the I, V, IV, III (47 specimens), text-fig. 149, (p. 134) is accounted for as a reversion to the character typical of some of the Cidaroida. The sum of these definitely accounted for variants, which is 525, subtracted from the total number of aberrant variants, which is 704, leaves only 179, or 0.37 %, which can be considered as distinct departures from the rule of ocular plate arrangement. Of these last, 56 specimens have oculars I, II insert (text-fig. 141, p. 134), which is the species character of *Gymnechinus pulchellus* and *robillardii* (text-figs. 177-179, p. 165), and 82 specimens have oculars V, IV insert (text-fig. 142, p. 134), which is a left-handed equivalent of the I, II insert. It is evident that even aberrants follow a quite definite arrangement and sporadic variants are extremely rare, only 41 cases as a whole in the 48,541 specimens of the order examined. Of these last, which are considered sporadic variants, ten specimens have ocular IV alone insert, three have III alone, and eight have ocular II alone insert; one specimen has oculars I, III insert, and four have V, III insert; four specimens have oculars I, V, III insert, and eleven have oculars V, IV, III insert. The detailed distribution of aberrants in families, genera, and species of the Centrechinoida can be seen in the table of aberrant variants, p. 164.

In the tables of ocular plate arrangement (pp. 100, 101, 142, 143, 154-163) are shown numerically the typical character of the species listed with the normal arrested and progressive variants, and in the right-hand column the number of aberrant variants, the details of which for the Centrechinoida are separately listed in the final table (p. 164). In the numbers given in the tables the denominator, in Arabic numerals, shows the number of specimens in which the given character was found and the numerator, in italic numerals, expresses the percentage which this number bears to the total number of specimens examined. In the last table are shown the characters of all aberrant variants tabulated in the Centrechinoida. It is noteworthy that in only a few species are such aberrants common, and it is a curious fact that has no obvious explanation, that most of such species occur off the west coast of South America. They are, namely, *Arbacia spatuligera* and *nigra*, and *Strongylocentrotus albus* and *gibbosus*. In the table of aberrants (p. 164) it is a striking fact as there brought out that certain aberrant variations are a characteristic of definite species or families in the order. In all of the tables of ocular plate arrangement the species within the genus are arranged on the basis of the number of oculars insert or its frequency as a variant. When no difference was observed they are arranged alphabetically. In the text they are considered in the same sequence.

The Cidaroida of the Mesozoic rarely have the oculars and genitals preserved, but they were found in seven specimens, all alike in character. The oculars are all exsert in a choice specimen of *Cidaris florigemina* from the Coral Rag, near Calne, in the Jermyn St. Museum; and in two specimens of *Cidaris sceptifera*, from the Chalk, one being in the Jermyn St. and the other in the British Museum. The same structure is shown in *Cidaris coronata* (text-fig.

TEXT-FIGS. 58-60.—Ocular plate arrangement in Cidaridae.

58. *Diplocidaris desori* Quenstedt. White Jura, Sontheim. Stuttgart Museum Coll., 9,778. All oculars exsert.

59. *Cidaris affinis* Philippi. Naples Station. Diam. 30 mm. R. T. J. Coll., 643. $\times 3$. All oculars insert, the local character of this species.

60. The same specimen, internal view. All oculars exsert as in the young and in the Jurassic. The madreporite has one large madreporic pore as in the young (Plate 2, fig. 3), not many pores as on the exterior of same plate.

164) and *Diplocidaris desori* (text-fig. 58). In both species the oculars are strongly exsert. The specimen of *Cidaris coronata* (text-fig. 164, p. 149), which is in the Stuttgart Museum, is exceptionally perfect for plates of the periproct, which are very rarely preserved in the Mesozoic. The character of having all the oculars exsert is seen in the young of Recent cidarids. It also occurs as the adult character of some Recent species and as an arrested variant in species typically having some oculars insert as seen in the table, pp. 100, 101.

Cidaris abyssicola (74 specimens) has typically all oculars strongly exsert, but in two specimens all the oculars are narrowly insert. It is remarkable that the only variants in this species should have this extreme character.

*Cidaris cidaris*¹ is apparently a rare species. Ten specimens were studied, in nine of which all oculars are strongly exsert. Four of these were kindly sent me by Dr. Mortensen. One specimen has oculars I, V, IV insert as a progressive variant.

Cidaris affinis is a difficult and interesting species presenting an exceptional amount of variation. In the form from the West Indies and Florida in 161 specimens in the U. S. National Museum, identified by Dr. Mortensen, the typical character by a small majority is for all oculars to be exsert as in the young, and in the adults of Jurassic species. There is, however, great variation, and only 30% have the typical species character of this locality. As all exsert is the character, cases with more or less oculars insert may be considered as progressive variants. In 18% ocular V only is insert, in 2% oculars V, I and in 7% oculars V, I, IV are insert, which is the species character of *Eucidaris tribuloides*. In 0.6% oculars V, I, IV, II are insert, like typical progressive variants of *Eucidaris tribuloides*; in 20% oculars I, V, IV, III are insert. This, which is a common character in this species, is uncommon in *tribuloides* and rare in the Centrechinoidea, where typically, if four plates are insert, it is the bivium and posterior pair of the trivium. In 20% all the oculars are insert; this, which is the extreme progressive variant for the southern form, is the typical character in the Mediterranean form of *Cidaris affinis*. Three specimens are aberrant with oculars V, IV, III insert. These are sporadic variants and are apparently imperfect cases of I, V, IV, III.

In the Mediterranean form of *Cidaris affinis* (frequently and incorrectly referred to *Dorocidaris papillata* = *Cidaris cidaris*) a quite different condition prevails. The ocular plates are all insert (text-fig. 59) as the typical condition in 53% of the 120 specimens seen. On the proximal side (text-fig. 60), however, the oculars are all exsert as in the young, and in adults of Jurassic species. This is of interest as showing a primitive character internally and a progressive externally in the same plates. It is due to the adoral beveling of periproctal plates over the genitals so that they extend further and present a different relation to the oculars

¹ This is the *Dorocidaris papillata* of authors. It is generally agreed that this is the *Echinus cidaris* of Linnaeus, and the type of *Cidaris*; also the three Recent species commonly attributed to *Cidaris s. s.* belong rather to *Eucidaris* Pomel (Bather; H. L. Clark, Ann. Mag. Nat. Hist., 1908-'09; Mortensen, 1909).

on the exterior from what they do on the interior of the test. The madreporite shows similar differential characters. On the exterior there are numerous fine pores, but on the interior only one large madreporic pore as in the young, a primitive character common to the whole family. Since typically in the Mediterranean form all oculars are insert, a specimen with any less must be considered an arrested variant. As such variants, 11% have all oculars exsert like the dominant character in the West Indian form, 4% have V only insert, 4% have V and I, the bivium, 10% have V, I, IV, and 14% have V, I, IV, III insert. Of aberrants there are five specimens, 4%. Of these, one has V, IV only insert, two have V, I, III, and two have V, IV, III insert.

Cidaris affinis is an important species in these studies because it shows strongly the character of V, I, IV, III insert when four plates meet the periproct, instead of V, I, IV, II. The same is probably true of a number of species in this order. Messrs. Agassiz and Clark (1907, p. 40) in their *Acanthocidaris hastigera* give V, I, IV, III insert as the species character, but do not say how many specimens showed it. It would be interesting to know, as it is the only species of echinoid known in which this is the character, as far as I am aware.

Eucidaris metularia has typically all oculars exsert, but in 39 specimens, two have V, I, IV insert as a progressive variant. *Eucidaris thouarsi* has typically V, I, IV insert, but the observations show a wide range of characters from all exsert to all insert. This species is very close to *Eucidaris tribuloides* of the West Indies. In both species oculars V, I, IV are typically insert, but in *thouarsi*, arrested variants are common, progressive variants less frequent; while in *tribuloides*, arrested variants are rare and progressive variants common, indicating that *thouarsi* is the more primitive of the two closely related species. Of *Eucidaris tribuloides* 849 specimens were studied, and they present most interesting characters. In the young of a few mm. in diameter (text-fig. 61) all the oculars are strongly exsert and there are few madreporic pores. The full number of oculars travels in very early. In the adult typically (58%), oculars V, I, IV are insert (text-fig. 66). The variations of the adult as seen in the large series studied are most interesting as the variants cover nearly the whole range of characters occurring as species features in all regular Echini known from the Lower Carboniferous to the present time.¹ The arrested variants are relatively rare, but progressive variants are common. Of arrested variants, in 0.6% all oculars are exsert (text-fig. 62), as in the young and the adult

TEXT-FIG. 61.—*Eucidaris tribuloides* (Lamarck). Florida. Diam. 5 mm. $\times 12$. R. T. J. Coll., 645. Young individual. No genital and but few madreporic pores, all oculars exsert.

¹ The only known exceptions are *Gymnechinus* and *Strongylocentrotus gibbosus*, in both of which this area is peculiarly modified and typically has an aberrant arrangement of oculars (text-figs. 154-157, p. 145, and 177-179, p. 165).

TEXT-FIGS. 62-71.—Ocular plate arrangement in *Eucidaris tribuloides* (Lamarck).

62. Jamaica. Diam. 38 mm. R. T. J. Coll., 798. All oculars exsert.
63. Jamaica. Diam. 33 mm. R. T. J. Coll., 799. Ocular V insert.
64. Jamaica. Diam. 35 mm. R. T. J. Coll., 800. Ocular I insert, genital 3, plates $\times'$, and genital 4, plates $\times$, are split by secondary sutures.
65. Nassau, Bahamas. Diam. 32 mm. R. T. J. Coll., 646. Oculars V, I insert. Figures 62-65 all arrested variants.
66. Nassau. Diam. 47 mm. R. T. J. Coll., 647. Oculars V, I, IV insert, the typical character.
67. Nassau. Diam. 52 mm. R. T. J. Coll., 648. Oculars V, I, IV, II insert.
68. Nassau. Diam. 40 mm. R. T. J. Coll., 649. All oculars insert.
69. Jamaica. Diam. 35 mm. R. T. J. Coll., 801. Oculars V, I, IV, III insert. Figures 67-69 all progressive variants.
70. Nassau. Diam. 47 mm. R. T. J. Coll., 654. Seen from exterior. The genital has many madreporic pores.
71. The same specimen seen from interior. The genital has only one large madreporic pore, and the genital pore is larger than on the exterior. All figures $\times 3$.

of species that typically have all oculars exsert. In three specimens (0.4%) ocular V alone is just insert (text-fig. 63) and in one specimen ocular I alone is insert (text-fig. 64), a condition seen often as a first stage of incoming of oculars in development; but as V insert is a frequent variant in the order, probably it typically comes in first in this species. In 3% oculars V, I are insert (text-fig. 65). These are all arrested variants. As progressive variants instead of the typical three plates, oculars V, I, IV, II are insert in 8% (text-fig. 67). This is of interest as these plates are the bivium and posterior pair of the trivium marking the bilateral symmetry of regular Echini. In 4% oculars V, I, IV, III are insert (text-fig. 69). This arrangement of four plates is relatively rare in *E. tribuloides* while it is a common variant in *Cidaris affinis* as there discussed. In 25% all oculars are insert (text-fig. 68). This is the extreme progressive variant of *tribuloides*, and is comparable to the typical character of *Phyllacanthus baculosa* (text-fig. 169, p. 149), or other species in which typically all oculars are insert. In only two specimens out of the 849 examined was the arrangement aberrant. In these variants one has oculars I, IV, III insert, V, II exsert; the other has oculars V, IV, III insert, I, II exsert. Both are sporadic variants and evidently cases of incomplete V, I, IV, III insert. In studying the specimens they were tabulated in lots of one hundred each, and it is worth noting that the percentage of the typical arrangement and the variations came out in each lot with hardly any difference, and the same regularity occurred in most species studied.

In *Goniocidaris nutrix* (text-fig. 72), typically (86%) the oculars are all fully exsert and a ring surrounds each ocular pore. This ring is a striking character not existent in *Goniocidaris*

TEXT-FIGS. 72-74.—Ocular plate arrangement in Cidaridae.

72. *Goniocidaris nutrix* (Wyville Thomson). Kerguelen Island, Antarctic. Diam. 27 mm. R. T. J. Coll., 743. $\times 4$. All oculars exsert, elevated ring around ocular pores, genital pores huge.
73. *Goniocidaris canaliculata* A. Agassiz. Falkland Islands. Diam. 24 mm. R. T. J. Coll., 744. $\times 4$. All oculars insert (compare with young, Plate 2, fig. 3).
74. The same. Falkland Islands. Diam. 22 mm. R. T. J. Coll., 745. $\times 4$. Genitals very low, genital pores reaching beyond plates.

Table of Typical Ocular Plate Arrangement and Variation in the Cidaroida.

Number of specimens.	Order Cidaroida Cidaridae	All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	Oculars I, V, IV, III insert; II exsert.	All oculars insert.	Arrangement of oculars aberrant.
2	<i>Cidarid coronata</i> Goldfuss. Jurassic, Nattheim and Sontheim. (Text-fig. 164.)	$\frac{100}{2}$ *								
74	<i>Cidarid abyssicola</i> (A. Agassiz). Florida, 100-200 fathoms.	$\frac{97}{72}$							$\frac{3}{12}$	
10	<i>Cidarid cidaris</i> (Linné). Off coast of Norway and Sweden.	$\frac{90}{9}$				$\frac{10}{1}$				
281	<i>Cidarid affinis</i> Philippi. Cuba to Yucatan, 45 fathoms; Florida (161 specimens).	$\frac{30}{48}$	.....	$\frac{18}{29}$	$\frac{2}{3}$	$\frac{7}{12}$	$\frac{0.6}{1}$	$\frac{20}{32}$	$\frac{20}{33}$	$\frac{2}{3}$
	The same. Mediterranean (120 specimens). (Text-figs. 59-60.)	$\frac{11}{13}$	.....	$\frac{4}{5}$	$\frac{4}{5}$	$\frac{10}{12}$	.....	$\frac{14}{17}$	$\frac{53}{63}$	$\frac{4}{5}$
39	<i>Eucidaris metularia</i> (Lamarek). Mauritius; Samoa; Hawaiian Islands.	$\frac{95}{37}$	.....			$\frac{5}{2}$				
34	<i>Eucidaris thouarsi</i> (Valentin). Gulf of California; Panama.	$\frac{15}{5}$	.....	$\frac{9}{3}$	$\frac{18}{6}$	$\frac{47}{16}$		$\frac{6}{2}$	$\frac{6}{2}$	
849	<i>Eucidaris tribuloides</i> (Lamarek). Jamaica; Bahamas; Florida; Bermuda. (Text-figs. 62-69, 176.)	$\frac{0.6}{5}$	$\frac{0.1}{1}$	$\frac{0.4}{3}$	$\frac{3}{28}$	$\frac{58}{493}$	$\frac{8}{72}$	$\frac{4}{36}$	$\frac{25}{209}$	$\frac{0.2}{2}$
7	<i>Goniocidarid nutrix</i> (Wyville Thomson). Kerguelen Island; Antarctic. (Text-fig. 72.)	$\frac{86}{6}$	.....						$\frac{14}{1}$	
17	<i>Goniocidarid tubaria</i> (Lamarek). Australia.	$\frac{12}{2}$	.....	$\frac{6}{1}$		$\frac{35}{6}$		$\frac{6}{1}$	$\frac{41}{7}$	
7	<i>Goniocidarid canaliculata</i> A. Agassiz. Port William; Falkland Islands; Patagonia. (Text-figs. 73-74.)							$\frac{14}{1}$	$\frac{86}{6}$	
3	<i>Goniocidarid biserialis</i> (Döderlein). Japan.								$\frac{100}{3}$	
5	<i>Phyllacanthus imperialis</i> (Lamarek). Gaspar Straits, Dutch East Indies.	$\frac{100}{5}$								
6	<i>Phyllacanthus thomasi</i> A. Agassiz and Clark. Hawaiian Islands.	$\frac{17}{1}$	.....	$\frac{17}{1}$		$\frac{33}{2}$			$\frac{33}{2}$	

Table of Typical Ocular Plate Arrangement and Variation in the Cidaroida (continued).

Number of specimens.	Order CIDAROIDA (continued). Cidaridae (continued).	All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	Oculars I, V, IV, III insert; II exsert.	All oculars insert.	Arrangement of oculars aberrant.
17	<i>Phyllacanthus annulifera</i> (Lamarek). Australia.	.....	.....	6* 1*	.....	18 3	12 2	12 2	53 9	.....
106	<i>Phyllacanthus baculosa</i> (Lamarek). Mauritius. (Text-figs. 169, 176, Plate 3, figs. 3, 4.)	.....	.....	.....	.....	1 1	1 1	.....	98 101	.....
1	<i>Diplocidaris desori</i> Quenstedt. Jurassic, Sontheim. (Text-fig. 58.)	$\frac{100}{1}$	.....	.....	.....	.....	.....	.....	.....	.....
1	<i>Diplocidaris gigantea</i> Desor. Jurassic, Besançon.	$\frac{100}{1}$	.....	.....	.....	.....	.....	.....	.....	.....
1,459		207	1	43	42	548	76	91	441	10

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

canaliculata, and I know it only in *Porocidaris milleri* A. Agassiz, as figured by Mr. Agassiz (1904). The genital pores are relatively huge, break through the confines of the genital plates and impinge upon the interambulaera. One specimen in the seven examined has all the oculars insert like the typical character of *canaliculata*.

In *Goniocidaris tubaria*, 17 specimens, all the oculars are insert in 41%, but there is considerable variation. In 12% all the oculars are exsert, as in *G. nutrix*, in 6% ocular V, in 35% oculars V, I, IV, and in 6% oculars V, I, IV, III are insert. The sequence of coming in is apparently V, I, IV, III, II.

The character of the apical disc in *Goniocidaris canaliculata* is of especial interest as the very young was studied carefully by Lovén (1892) and is here figured (Plate 2, figs. 1-3). Of seven adults the oculars are all broadly insert in six specimens (text-figs. 73, 74), and in the seventh, oculars V, I, IV, III are insert. There is no elevated ring around the ocular pores and the genital plates and pores are small, not large, in distinction from *G. nutrix*. The genital pores, however, extend beyond the limits of the plate as in *nutrix*. The oculars are broadly

exsert in the very young (Plate 2, fig. 3), as in the Jurassic. In a series of eight young specimens from Patagonia in the American Museum of Natural History, varying from 15 to 20 mm. in diameter, the oculars are slightly or more strongly exsert in all but one, the largest, in which ocular V alone is insert. The genitals are high in the young rather than low as in the adult, therefore more like typical cidarids, and all or part of the genital pores are wanting in the smaller specimens. This all indicates that adult characters are taken on late in this species, indeed much later than usual in Echini. In adults the genitals are relatively the lowest, especially those shown in text-fig. 74, of any genitals seen in Echini; perhaps in some way correlated with the peculiar brooding habit of this species. Mr. Agassiz (1873, p. 396) said of *G. canaliculata* that the genital plates are in contact. He included (1881, p. 44), however, *Goniocidaris nutrix* in this species, and it is possible that his observation of exsert oculars was based on *nutrix*, in which it is characteristic. As I find six out of seven adults with all oculars insert, it is fair to assume that as the specific character. In *Goniocidaris biserialis* all the oculars are insert in three specimens.

In *Phyllacanthus* there is wide range in species as to the insertness of oculars, as shown in the table; but with one exception only a few specimens were studied. In *Phyllacanthus imperialis* oculars are typically all exsert. In *P. thomasi*, in 33%, oculars V, I, IV, or all, are insert, but one specimen has all exsert and one has V only insert, these last two being the largest specimens of the species seen. In *P. annulifera* oculars are typically all insert, as seen in 53% of the 17 specimens. Of arrested variants 6% have ocular V only insert, 18% have I, V, IV, 12% I, V, IV, II, and 12% I, V, IV, III insert. In these characters the species is distinctly more primitive than the next. In *Phyllacanthus baculosa* (106 specimens) the oculars are all insert in 98% of the cases (text-fig. 169, p. 149). In one exception oculars V, I, IV are insert (Plate 3, fig. 3), for this species an arrested variant, comparable to the typical character of *Eucidaris tribuloides* (text-fig. 66). In another specimen oculars V, I, IV, II are insert and III exsert (Plate 3, fig. 4). This arrested variant is especially interesting as it is like the progressive variant of *Eucidaris tribuloides* (text-fig. 67), and also as it indicates that III is the last ocular to become insert as in that species and in the Centrechinoida. *Phyllacanthus baculosa* with all oculars insert is in this feature like the majority of Palaeozoic species, and like progressive variants of those in its own order that typically have fewer oculars insert. It is the only species of Echini with all insert typically in which a considerable number of specimens have been studied, and it is interesting to see that its variants, though so few, accord with the characters of associated types.

Considering the ocular arrangement in the Cidaroida as a whole, it is seen that they follow very closely the order of insertness that is characteristic of the group, but yet show a very wide diversity of arrangement within the species. The variants skip about within the limits of variation in a degree that is unknown in the Centrechinoida, yet aberrant variants are

relatively rare in the Cidaroida. The character of the apical disc in the Palaeozoic Cidaridae (Miocidaris) is unknown and would be most interesting to ascertain.

Turning to the Centrechinoida, it is found that in this order the arrangement of the ocular plates as regards insertness is much more definite and constant than in most of the Cidaroida. Taking up the first suborder Aulodonta,¹ we find that in the Mesozoic Hemicidaridae the leading character is for all the oculars to be exsert, as shown in the first two species listed in the table. In *Hemicidaris intermedia* (169 specimens) the oculars are exsert in 89% (text-fig. 75), but 13 specimens, 8%, are progressive variants with ocular I insert, and in five specimens, 3%, the bivium is insert. In *H. crenularis* (58 specimens) 81% have all oculars exsert, but 16% are progressive variants with ocular I insert, and 2% progressive with oculars I, V insert, like the typical character of the next higher species. One specimen is aberrant with ocular III alone insert, a very rare variation seen in only two other sea-urchins (table, p. 164).

In *Hemicidaris luciensis* typically, 56%, the bivium is insert (text-fig. 77) like the most progressive variants of *H. intermedia*. Seven specimens in 16, however, are arrested variants, two with all oculars exsert, the dominant character of the genus, and five with ocular I insert (text-fig. 76), like the progressive variants of *Hemicidaris crenularis* and *intermedia*. *Hemicidaris langrunensis* likewise has typically the bivium insert, 67%, as a species character, but of 18 specimens, 11% have all the oculars exsert and 22% have ocular I only insert, as arrested variants. In *Hemidiadema stramonium* (10 specimens) the oculars are typically all exsert, 90%, but 10% are progressive with ocular I insert. In *Asterocidaris minor* (text-fig. 78), *Goniopygus peltatus*, and *Glypticus hieroglyphicus* (text-fig. 79) the oculars are strongly exsert in all of the 134 specimens seen (table, p. 154).

TEXT-FIGS. 75-79.— Ocular plate arrangement in the Hemicidaridae.

75. *Hemicidaris intermedia* (Fleming). Coral Rag, Calne, Wilts, England. Diam. 32 mm. R. T. J. Coll., 720. All oculars exsert, the typical character.

76. *Hemicidaris luciensis* d'Orbigny. Jurassic, Bath sur Mer. Diam. 22 mm. R. T. J. Coll., 718. Ocular I insert, an arrested variant.

77. The same. Diam. 25 mm. R. T. J. Coll., 719. Oculars I, V insert, the typical character.

78. *Asterocidaris minor* Cotteau. Jurassic, Sollies, France. G. Boehm Coll., Freiburg i. B. Oculars all exsert.

79. *Glypticus hieroglyphicus* Agassiz. Coral Rag, St. Pierre, Neuchâtel. Diam. 19 mm. R. T. J. Coll., 606. Oculars all exsert. All figures $\times 4$.

¹ The suborders of the Centrechinoida are new divisions defined and discussed in the section on classification and p. 183.

Of the Aspidodiadematidae 123 specimens, including four species, have been examined. In all the oculars are widely insert, as in *Dermatodiadema antillarum* (text-fig. 80). The oculars are relatively exceptionally broad and large, as pointed out by Mr. Agassiz (1904, p. 59, 75),

TEXT-FIG. 80. — *Dermatodiadema antillarum* A. Agassiz. West Indies, 955 fathoms. Diam. 9 mm. R. T. J. Coll. 670. $\times 6$. All oculars broadly insert.

and, as he notes, are comparable to the Palaeoecchinidae in that all meet the periproct. They differ, however, in their relatively great size, especially their width, as compared with the genitals. The genitals are peculiar in that the pores are large and nearly or quite in the middle of each plate. The apical disc in the Aspidodiadematidae is relatively very large, being about 30 to 60 % of the diameter of the test. In this it differs radically from the Palaeoecchinidae in which the apical disc is relatively small, usually being less than 20 % of the diameter of the test.

In the Mesozoic Centrechinidae the ocular plates are all exsert typically, in strong distinction to living species of the family. Of 18 specimens of the Jurassic *Pseudodiadema pseudodiadema*, in 89 % all oculars are exsert (text-fig. 81), but in 11 % ocular I is insert (text-fig. 82), a progressive variant. It is of interest to note that this ocular, I, is the first to become insert in the development of the recent *Centrechinus* (text-fig. 90). In the Jurassic *Magnosia* (text-fig. 83), *Cottaldia*, *Phymechinus* (text-fig. 84), and *Pedina*, all oculars are exsert as usual in Mesozoic species of the family¹ excepting one specimen of *Phymechinus* in which the bivium is insert. Of Jurassic *Stomechinus* several species, including 82 specimens, were studied. Usually all the oculars are exsert as in *S. bigranularis* (text-fig. 85). In a few cases, six in all, ocular I or V, or I and V, are insert as in text-fig. 86. These are distinctly progressive variants for the species and the geological horizon, and are comparable to the second and third stages in the development of oculars in recent *Centrechinus*, where one ocular or the bivium is insert as in text-figs. 90, 91 (table, p. 155).

In the Mesozoic *Polycyphus* and *Orthopsis* (text-fig. 87), oculars were all exsert in the 51 specimens seen, except that in one specimen of *P. normannus* ocular I is insert.

In *Centrechinus setosus*² we have the type species of the family and therefore one of much importance. Mr. Agassiz early recognized several species of the genus; in the Revision he recognized only two. Dr. Mortensen (1904) revived the earlier species and Messrs. A. Agassiz and Clark (1908) followed him in taking up the older divisions of the genus. Having had specimens of the several species, I confess I cannot recognize the specific distinctions as diagnostic

¹ Text-figs. 78 and 82-84 were drawn from specimens in the personal collection of Professor G. Boehm of Freiburg i. B., who kindly gave the opportunity to study them and other material.

² For the change of name from *Diadema setosum* to *Centrechinus setosus*, see footnote pp. 27, 28.

and here consider the several forms from the Pacific and Atlantic as all referable to *C. sclosus*. In this species we find most interesting characters in regard to oculars, for the phases seen as stages in development and variation in the adult cover the whole range of characters seen in

- TEXT-FIGS. 81-87.— Ocular plate arrangement in Mesozoic Centreechinidae.
81. *Pseudodiadema pseudodiadema* (Lamarek). Coral Rag, Yonne, France. Diam. 20 mm. R. T. J. Coll., 716. $\times 8$. All oculars insert, typical character.
82. The same. Corallien, Trouville. G. Boehm Coll., Freiburg i. B. $\times 4$. Ocular I insert, a progressive variant.
83. *Magnosia punctulata* (Lamarek). Oxford, Berner Jura. G. Boehm Coll., Freiburg i. B. $\times$ about 20. All oculars exsert.
84. *Phymechinus mirabilis* Agassiz. Oxford, Berner Jura. G. Boehm Coll., Freiburg i. B. $\times 4$. All oculars exsert, typical character.
85. *Stomechinus bigranularis* Lamarek. Inferior Oolite, Broad Windsor, Dorset. Diam. 47 mm. R. T. J. Coll., 721. $\times 4$. All oculars exsert, typical character.
86. The same. Diam. 48 mm. R. T. J. Coll., 715. $\times 4$. Oculars I, V insert, a progressive variant.
87. *Orthopsis miliaris* (d'Archiac). Cretaceous, Les Tamarins, Algiers. Diam. 20 mm. R. T. J. Coll., 717. $\times 8$. All oculars exsert, typical character.

the fossil and recent members of the family. In a very young specimen (text-fig. 88) all the oculars are fully exsert and this early stage may be compared with the adult Jurassic *Pseudodiadema* (text-fig. 81). In an older specimen (text-fig. 89) the oculars are still all exsert, but

I is nearly in. In text-fig. 90 ocular I is insert, the others all exsert, a developing condition like the progressive variant of Jurassic *Pseudodiadema* (text-fig. 82). A later stage is shown in text-fig. 91, in which oculars I and V are insert and IV is nearly in. This may be compared with the extreme progressive variant in Jurassic *Stomechinus* (text-fig. 86), in which also the bivium is insert. A still later stage (text-fig. 92) has oculars I, V, IV insert, II, III exsert, and

TEXT-FIGS. 88-92.—Development of ocular plate arrangement in *Centrechinus scotus* (Leske).

88. Bahamas. Diam. 8 mm. R. T. J. Coll., 672. $\times 10$. Oculars all strongly exsert, marginal plates of the periproct are large, a youthful character, compare text-fig. 98. See p. 174.
89. St. Thomas, West Indies. Diam. 33 mm. R. T. J. Coll., 755. $\times 5$. Oculars still all exsert.
90. The same. Diam. 33 mm. R. T. J. Coll., 756. $\times 5$. Ocular I insert.
91. The same. Diam. 31 mm. R. T. J. Coll., 757. $\times 5$. Oculars I, V insert.
92. The same. Diam. 31 mm. R. T. J. Coll., 758. $\times 5$. Oculars I, V, IV insert. Ambulacral plates simple dorsally above the 18th, which is the first compound plate (p. 55).

this, though only 31 mm. in diameter, has taken on the full species character in this respect. Interesting features of the corona are shown also in text-fig. 92. The ambulacral plates near the ocular are all simple as in cidarids, the first compound plate being the 18th from the base of the corona, as indicated. In the adult specimen (text-fig. 94) a similar condition of simple plates is seen in the placogenous zone, and the first compound plate is the 24th from the base of the corona. This condition of simple plates in the placogenous zone was pointed out by Lovén (1874), but is much clearer in *Centrechinus* than in many genera. The development of the interambulacrum is shown in a similar manner in text-fig. 92; plates 11 and 12 are nearly

smooth and 10 has the primary tubercle. In the adult (text-fig. 94), plates 14 to 16 are smooth and 13 has the primary tubercle. This is in accordance with what I showed (Jackson, 1899) as localized stages in development in *Strongylocentrotus* and *Arbacia*, that the young last added plates are simple, and that differential characters are progressively added as the plates grow older and are pushed ventrally by newly added plates on their dorsal border.

It would be extremely interesting to study a large series of young developing *Centrechinus setosus*. I succeeded in getting 110 specimens from 8 to 40 mm. in diameter from the West Indies, Bermuda, and the Pacific. Of this series, as shown in the table (p. 155), 23% have all oculars exsert, 5% have I insert, 9% I and V, and 55% have the adult typical character of I, V, IV insert. Progressive variants in this immature series are infrequent, as would be expected; 5% have I, V, IV, II insert, and 3% have all oculars insert. With later growth unquestionably more oculars would have come in in some of the specimens, so as to give the usual adult percentage of progressive variants. There are two aberrant variants, one with oculars V, IV, and one with I, V, IV, III insert.

TEXT-FIGS. 93-95.—Ocular plate arrangement in *Centrechinus setosus* (Leske).

93. Bermuda. Diam. 85 mm. R. T. J. Coll., 686. $\times 2.5$. Oculars I, V, IV insert, the species character.

94. Florida. Diam. 70 mm. R. T. J. Coll., 687. $\times 2.5$. Oculars I, V, IV, II insert, a progressive variant, ambulacral plates simple dorsally above the 24th, which is the first compound plate (pp. 56, 174).

95. Florida. Diam. 82 mm. R. T. J. Coll., 688. $\times 2.5$. All oculars insert, a progressive variant.

The development of ocular plates of *Centrechinus* being as above described, the adult shows striking features as a matter of individual variation. All individuals considered under variation were not fully grown, any more than in other species, but all here considered are

40 mm. or more in diameter, at which size full species characters are attained in development. From several localities 1,168 specimens were studied. Of these, 57% have oculars I, V, IV insert (text-fig. 93), which is strongly the species character, and little variation from this percentage was seen in specimens from any locality. The variations from the typical cover the whole range of characters seen in development and also adults of all species of the family, fossil and living. Two arrested variants have all oculars exsert, a feature seen in the young (text-fig. 88) and in the adults of Jurassic species (text-fig. 81). Two specimens have ocular I only insert, and all other oculars exsert, though V and IV are barely exsert. This character can be compared with the second stage in development (text-fig. 90) and with progressive variants of Jurassic species where I also is insert (text-fig. 82). These extreme arrested variants of *Centrechinus* are small individuals (the all exsert 50 mm., the I only insert 51 mm. in diameter). One specimen has ocular V alone insert, an exceptional character. Eleven specimens, or 1%, have as arrested variants only oculars I, V insert, being comparable to the young (text-fig. 91) and to an extreme progressive variant in Jurassic species (text-fig. 86). As progressive variants of *Centrechinus setosus*, 17% have oculars I, V, IV, II insert (text-fig. 94), the bivium and posterior pair of the trivium marking the bilateral symmetry as an order of developing parts.

TEXT-FIGS. 96-98.—Ocular plate arrangement in the Centrechinidae.

96. *Centrostephanus rodgersi* A. Agassiz. Parramatta, N. S. W. Diam. 110 mm. R. T. J. Coll., 750. $\times 2$. Oculars I, V, IV insert, madreporite split, young ambulaeral plates simple (p. 174).

97. *Centrostephanus longispinus* (Philippi). Naples Station. Diam. 27 mm. R. T. J. Coll., 751. $\times 2$. All oculars insert, plates of periproct numerous and minute, excepting a few large plates on the periphery of the area (p. 174).

98. *Chaetodiadema pallidum* A. Agassiz and Clark. Hawaiian Islands. Diam. 65 mm. R. T. J. Coll., 760. $\times 2$. All oculars widely insert, plates of periproct large (p. 174).

In 22% all the oculars are insert (text-fig. 95). This character, which is a progressive variant of *Centrechinus setosus*, is the typical feature of *Echinothrix*, *Centrostephanus longispinus* (text-

fig. 97), *Astropyga* (text-fig. 99), and *Chaetodiadema* (text-fig. 98). There are 33 aberrants, 3%. Thirty-one of these have I, V, IV, III insert. This character is common in cidarids as discussed, but is rare in the Centrechinoida, most of the cases seen occurring in this species. One aberrant has oculars I, IV insert, V being excluded by the fusion of genitals 4, 5, as in text-fig. 144; and one aberrant has V, IV, III insert, evidently an imperfect I, V, IV, III, and a very rare variant, which, however, is the species character of *Strongylocentrotus gibbosus* (text-fig. 156). While three plates insert is strongly the character of *C. setosus*, in no case were oculars I, V, II insert, which is so markedly a character of the Echinidae and Strongylocentrotidae. It is a remarkable fact that the aberrants of this species fall so definitely in one place, I, V, IV, III insert, there being only three exceptions to this in the whole 1,278 specimens examined.

In *Echinothrix calamaris* (11 specimens) oculars are all insert in ten, and in one I, V, IV are insert like the typical character of *Centrechinus setosus*. In *Echinothrix diadema* (18 specimens) all oculars are insert.

Centrostephanus asteriscus is interesting as the only Recent species of the Centrechinidae in which the oculars are all exsert in the adult, as they are typically in Jurassic species of the

TEXT-FIGS. 99-101.—Ocular plate arrangement in Centrechinidae and Echinothuriidae.

99. *Astropyga pulvinata* (Lamarek). Gulf of California. Diam. 94 mm. R. T. J. Coll., 740. $\times 4$. Oculars all insert.

100. The same, section of ambulaeral plates showing adoral imbrication, and of interambulaeral plates showing aboral imbrication (p. 74).

101. *Asthenosoma ijimai* Mortensen. Tokyo, Japan, 55 fath. Diam. 105 mm. R. T. J. Coll., 762. Oculars all insert, genitals, split up, especially ventrally (p. 168).

family. In this respect it is therefore primitive; only two specimens were seen. *Centrostephanus rodgersi* (text-fig. 96) has typically oculars I, V, IV insert, but in twelve specimens, three have I, V, IV, II, and one has all oculars insert as progressive variants. The range of characters is therefore the same as the dominant ones of *Centrechinus setosus*. The specimen figured shows a secondary splitting of the madreporite and also unplated tissue ventral to the apical disc, both of which features are seen in Echinothuriidae. In *Centrostephanus longispinus* (text-fig. 97) all the oculars are insert; only four specimens were seen, but if four agree in a character, it is strong evidence that the typical feature is ascertained. The plates of the periproct are numerous and minute; a few large plates lie on the periphery mainly over the oculars.

Astropyga is a very interesting type as an extreme form of the family. All the oculars are broadly insert (text-fig. 99). In this type the plates are imbricate (p. 74) as seen in text-fig. 100, and leathery tissue exists between the oculo-genital plates as in Echinothuriidae, yet the genus is clearly one of the Centrechinidae as shown by the character of the peristome.

In *Chaetodiadema pallidum* the plates are excessively thin and imbricating. The ocular plates are all broadly insert (text-fig. 98), almost exactly as in *Melonechinus* (Plate 56, fig. 6). No difference was observed in 36 specimens seen. The periproctal plates on the outer border are exceptionally large, but minute in the center, in this feature being like the young of *Centrechinus* (text-fig. 88).

Of the Echinothuriidae, only a few specimens have been studied. In *Asthenosoma ijimai* (text-fig. 101) the oculars are all broadly insert. Ocular and genital plates meet in a continuous ring, but are deeply covered on their lateral borders, as are also in part the coronal plates, by living tissue. Genital plates are split up ventrally into many minute plates and the madreporite is split so that the pores exist in several dissociated plates. This type makes a rather close approach to the character of *Astropyga*.

In *Phormosoma placenta*, when 3 mm. in diameter, the genitals are in contact and all oculars exsert (Plate 3, fig. 8), as shown by Dr. Mortensen (1903, p. 174; 1907, text-fig. 1, p. 24). This is much like the condition in Jurassic *Phymechinus* (text-fig. 84). Later the oculars travel in and meet the periproct, the oculo-genital ring being continuous as in progressive variants of *Centrechinus* (text-fig. 95), and in the typical condition of *Chaetodiadema* (text-fig. 98). Mr. Agassiz (1904) shows this early stage in *Phormosoma* and in a beautiful series of figures its development to the adult condition (text-fig. 170, p. 149), in which the genitals and oculars are separated so that the periproct comes in contact with the interambulacra (p. 63). This character of separation of oculars and genitals occurs as a feature in regular Echini only in the Echinothuriidae, but has been seen as a variant in *Strongylocentrotus* (Plate 6, fig. 5, and Plate 5, fig. 15). In the corona of *Phormosoma* (text-fig. 170, p. 149), in the placogenous zone, the ambulacral plates are simple and the young interambulacral plates originate against the oculars as usual in Echini. The suborder Aulodonta exhibits a wide

range of characters as regards oculars, from all exsert, the Jurassic and youthful character, to all insert, and finally oculars and genitals separated by an interspace, a condition occurring typically in no other regular Echini. The oculars reach the periproct in the sequence I, V, IV, II, III, whereas in the two other suborders a different sequence occurs in two of the families, the Arbaciidae and Echinometridae, in which the sequence is V, I and not I, V (see tables).

Considering the next suborder, the Stirodonta, we find in the Saleniidae the Mesozoic species of *Peltastes* have all oculars exsert (127 specimens), as in *Peltastes wrighti* (Plate 4, fig. 7). In *Salenia scutigera* (16 specimens) also all oculars are exsert, the same character being seen in many other Cretaceous species of the genus. In the Cretaceous *Salenia petalifera* (20 specimens) the oculars are all exsert in 95%, but in one specimen, 5%, ocular I is insert as a progressive variant, in this feature being like the typical character of Recent species of the family. Of many other species of Cretaceous Salenias seen, but not tabulated, all had the oculars exsert excepting one specimen of *Salenia clarki* (?) Forbes, in the Jernyn St. Museum, in which ocular I was insert.

TEXT-FIGS. 102-105.—Ocular arrangement in the Saleniidae (pp. 174, 175).

102. *Salenocidaris profundus* (Duncan). North of Tristan da Cunha, 1,425 fath. Diam. 10 mm. R. T. J. Coll., 667. $\times 4$. Ocular I insert, the typical character; the suranal plate is dorsal to genital 3.
103. *Acrosalenia spinosa* Agassiz. Cornbrash, Chippenham, England. Diam. 14 mm. R. T. J. Coll. $\times 8$. Oculars I, V insert, the typical character; the suranal plate is dorsal to ocular III.
104. *Acrosalenia hemiscidaroides* Wright. Forest Marble, near Malmsbury, England. Diam. 10 mm. R. T. J. Coll., 735. $\times 8$. Oculars I, V insert, the typical character; the suranal plate is dorsal to genital 3.
105. *Acrosalenia wiltoni* Wright. Bradford Clay, near Cirencester, England. Diam. 12 mm. R. T. J. Coll., 736. $\times 8$. All oculars insert, a progressive variant; the suranal plate is dorsal to ocular III.

The Recent species are very interesting in comparison. As Mr. Agassiz shows (1904, Plate 21, fig. 2), in the young of *Salenocidaris varispina*, all the oculars are exsert as in adults of Cretaceous species. Of adult *Salenia pattersoni* in 16 specimens, 69% have ocular I insert and 31% are arrested variants with all oculars exsert, like the character of the Cretaceous

species. The typical condition is shown in Plate 4, fig. 1. In this external view a number of fine madreporic pores are seen, but no ocular nor genital pores are visible. The specimen was cut in two and viewed from the interior (Plate 4, fig. 2); here ocular and genital pores are plainly visible, but in place of a number of fine madreporic pores as seen on the exterior, there is only one large madreporic pore, a condition similar to that in cidarids (text-figs. 59, 60, p. 95); also similar to the condition characteristic of the exterior of the plate in very young Echini (text-fig. 131, p. 129). In *Salenia cincta* (two specimens) ocular I is insert. In *Salenocidaris profundus* (ten specimens) typically, 70%, ocular I is insert (text-fig. 102), but in three specimens, all the oculars are exsert as in the young and in adults of Mesozoic species. *Salenocidaris varispina* (26 specimens) in 73% has ocular I insert (Plate 4, fig. 6), and 27% are arrested variants with all oculars exsert. In *Salenocidaris miliaris* (16 specimens) 81% have ocular I insert, and 19% all oculars exsert. All the evidence is that modern representatives of the Saleniidae have ocular I insert as a typical character, and more or less frequently have all oculars exsert as arrested variants, like their own young and the adults of Mesozoic species.

In the Jurassic *Acrosalenias* a much wider range of characters prevails. The oculars may be all exsert like the Cretaceous *Salenias*, as seen in *Acrosalenia aspera* (ten specimens). In *Acrosalenia decorata* (five specimens) the oculars are all exsert in 60%, but in 40% oculars I, V are insert, this as a progressive variant being comparable to the typical character of the next species. In *Acrosalenia spinosa* (101 specimens) typically, 92%, oculars I, V are insert (text-fig. 103). As arrested variants, in 1% all oculars are exsert, as in the lower species, *A. aspera*, and in 7% ocular I is insert like progressive variants of Cretaceous *Salenias* and also like the typical condition in Recent species (text-fig. 102). In *Acrosalenia hemicydaroides* (58 specimens) oculars I, V are insert in 86% (text-fig. 104). As arrested variants, 2% have all oculars exsert, 5% ocular I insert. Aberrant variants are rather frequent in this species, 7%. Of these, one specimen has oculars V, II insert, one has I, V, III insert, a rare variant in Echini, and two have oculars I, V, II insert. The species *Acrosalenia pustulata* is more progressive in character. Of 16 specimens, 63% have oculars I, V insert as a species character. Of arrested variants, only 6% have ocular I insert; 19% are progressive, with oculars I, V, IV, and 6% progressive, with I, V, IV, II insert. One specimen is an aberrant variant with oculars I, V, III insert, IV, II exsert, a rare character in Echini. In *Acrosalenia pseudodecorata* (text-fig. 168, p. 149), according to Cotteau (1875-'80), typically oculars I, V, IV, II are insert. This is interesting, as it is the only regular sea-urchin I know of in which this arrangement is a specific character, although it is a common or rare variant in a good many species; also, it is the same character that is found in the Cretaceous spatangoid *Ananchytes ovatus* (text-fig. 175). In *Acrosalenia wiltoni* (12 specimens), oculars I, V are insert as a species character in 58%; five of the specimens showing this character of the bivium insert are in the Jermyn St. Museum, observations on which were kindly sent me by my friend, Dr. Kitchin. Of this

species, one specimen, 8%, has ocular I only insert as an arrested variant; of progressive variants, one specimen has oculars I, V, IV insert, two, or 17% have I, V, IV, II, and one has all oculars insert (text-fig. 105). A large series of observations on this species would be most interesting. The wide range of characters of the Saleniidae and the progressive feature of the same, as shown in the table (pp. 156, 157), are striking.

Of the fossil Phymosomatidae I have only seen the ocular plates of *Phymosoma delamarci* of the Cretaceous. In ten specimens of this species all the oculars are insert (text-fig. 106), a very unusual Mesozoic character. In the Recent *Glyptocidaris* (*Phymosoma*) *crenulata* A. Agassiz, Mr. Agassiz (1873, p. 488, Plate 7a, fig. 8) says that two oculars reach the periproet. His photographie figure shows only ocular I insert, and the same condition of I insert exists in the only specimen I have seen, therefore apparently one or two oculars may be insert. On the basis of this evidence, ocular I enters the periproet first in the Phymosomatidae as in the Saleniidae, not ocular V as in the Arbaciidae. Additional observations on species of this family would be of much interest.

The Stomopneustidae of Mortensen with the one species, *Stomopneustes variolaris*, was set apart by that author (1903, p. 133) as a distinct family. I include the family here as its lantern has keeled teeth and epiphyses not meeting across the foramen magnum, thus referring it to the suborder Stirodonta. Other features of the lantern associate it closely with *Glyptocidaris* as described under consideration of the lantern. In *Stomopneustes variolaris* (64 specimens) typically, 70%, oculars I, V are insert (text-fig. 108). In 2%, ocular I only is insert as an arrested variant (text-fig. 107), and in 22%, oculars I, V, IV are insert as progressive variants (text-fig. 109). Aberrant variants are 6%, of which one specimen has ocular IV only insert, a very rare variant in Echini, and three have oculars I, V, II insert (text-fig. 110). The occurrence of I, V, II insert is of special interest, as this and *Acrosalenia hemicydaroides* are the only known species in which it has been found excepting in the Echinidae and Strongylocentrotidae, where it is a common character. This with other characters suggests a connection between the families (pp. 186, 214).

The Arbaciidae present interesting characters as regards ocular plates in their relations to the genitals. Some species are characterized by having all oculars exsert, others by having three plates insert. Those which have most oculars insert are geographically southern species. The order of incoming is V, I, IV, not I, V, IV, and this sequence is characteristic of this family and the Echinometridae (as here restricted) only in the order of the Centrechinoida. This is a striking distinction, and only two cases of I coming in before V were seen in over 2,900 Arbaciidae examined, as seen in the table, p. 158.

TEXT-FIG. 106. — *Phymosoma delamarci* (Desor). Senonian, Les Tamarins, Algiers. Diam. 29 mm. R. T. J. Coll., 737. $\times 4$. All oculars insert.

In *Arbacia stellata* (78 specimens) the oculars are typically all exsert, 95 %. In three specimens, 4 %, V is insert as a progressive variant, and in 1 % oculars V, I, IV are insert. This, although southern, on the basis of ocular plates, is the most primitive of the living species.

TEXT-FIGS. 107-110.—Ocular arrangement in *Stomopneustes variolaris* (Lamarek). Ceylon.
 107. Diam. 62 mm. R. T. J. Coll., 858. $\times 3$. Ocular I only insert, an arrested variant.
 108. Diam. 88 mm. R. T. J. Coll., 859. $\times 3$. Oculars I, V insert, typical character.
 109. Diam. 74 mm. R. T. J. Coll., 860. $\times 3$. Oculars I, V, IV insert, a progressive variant.
 110. Diam. 86 mm. R. T. J. Coll., 861. $\times 3$. Oculars I, V, II insert, an aberrant variant (p. 93).

Arbacia lixula (141 specimens) has 94 % with oculars all exsert, the typical character; 6 % are progressive variants, with V insert, and one specimen is aberrant with ocular IV alone insert, a very rare variant in Echini.

Of *Arbacia punctulata* I was fortunate enough, through the kindness of the Woods Hole Biological Laboratory and other sources, to examine 2,100 specimens from Woods Hole, Massachusetts. In this species typically, 87 %, all oculars are exsert (text-fig. 111). As progressive variants, 11 % have ocular V insert (text-fig. 112). Only two specimens, 0.1 %, have ocular I alone insert. In 0.3 % V and I are insert (text-fig. 113), and in 0.4 % V, I, IV are insert (text-fig. 114). This range of characters covers essentially the same series as seen in *Arbacia nigra*, the most progressive species of the genus; but the relative frequency of characters is radically different. In 0.6 % of the Woods Hole specimens the arrangement is aberrant. In nine out of the twelve aberrants found, the arrangement is V, IV alone insert, which is a quite common variant in this genus (see table, p. 164), but rare in other genera. One specimen has ocular IV alone insert, a very rare character, one has I, IV and one has I, III insert, the last a unique variant.

Arbacia punctulata, from Woods Hole, is distinctly more progressive in character than the two previous species. It is worth noting that in this species, as in most studied, the character was gathered from the first few examined and the commoner variants came along with great regularity, so that the percentages in 2,100 specimens vary very slightly from what they were

when only 100 were counted. Of course the rarer variants are usually found in only large series, and one cannot know whether they are rare or not without having examined large numbers. A series of 229 specimens of *Arbacia punctulata* from Florida is interesting for compari-

TEXT-FIGS. 111-114.—Ocular plate arrangement in *Arbacia punctulata* (Lamarek). Woods Hole, Massachusetts. All figures $\times 3$ (p. 175).

111. Diam. 31 mm. R. T. J. Coll., 681. All oculars exsert, typical character.

112. Diam. 42 mm. R. T. J. Coll., 682. Ocular V insert.

113. Diam. 31 mm. R. T. J. Coll., 683. Oculars V, I insert.

114. Diam. 38 mm. R. T. J. Coll., 684. Oculars V, I, IV insert. Figures 112 to 114 are all progressive variants.

son with those from the northern locality. In the Florida series, 76 % have all oculars exsert, 19 % have V alone insert, 2 % have V, I and 1 % have V, I, IV insert; 3 % have an aberrant arrangement, one specimen having ocular IV only insert, and five having V, IV insert. In comparing this with the northern form, best seen by the table (p. 158), it is obvious that the Florida form is markedly more progressive in ocular arrangement than the northern. Also in this respect it makes a closer approach to the character of the species occurring off the west coast of South America. A similar difference seen in the character of a species from different localities is shown also in several other species covering the commoner families of regular Echini.

Of the rare species *Arbacia dufresnii*, 67 specimens are listed in the table. Some others studied were omitted as too immature for the present consideration. The specimens are largely from San Antonio, East Patagonia, in the de Loriol collection at Geneva. In 87 % all oculars are exsert as the species character. As progressive variants, in 4 % ocular V is insert, and in 1 % oculars V, I are insert. Aberrant variants are quite frequent, 7 %, as in other South American species of the genus. Of these aberrants, two have ocular IV alone insert, and three have oculars V, IV insert, I, II, III exsert. This last is a relatively frequent aberrant variation in this genus. Eighteen specimens in the de Loriol collection which are considered too immature for tabulation have all the oculars broadly exsert. Of the specimens studied, most have the four periproctal plates characteristic of the genus; but two have three periproctal plates, four have five, two have six, and one has nine periproctal plates (compare text-figs. 200-205, p. 175).

Of the South American *Arbacia spatuligera* (76 specimens) in only 9 % are the oculars all

exsert. In 30% ocular V is insert, 14% V, I, and 33% V, I, IV. This last is the typical feature by a small margin. This is a curious case in which the typical character falls so nearly on two distinct points. It is interesting also that these two points are not structurally contiguous. A large number of observations would be interesting. There are ten aberrants, 13%, which is a very high percentage in the order, and these variants are all V, IV insert, a common aberrant in this genus. It quite probably may be considered an imperfect V, I, IV with I left out by failure to become insert. Mr. Agassiz (1873, p. 403) says of this species, "The ocular plates are in contact with the anal system." From his context this is evidently a misprint for *two* ocular plates. In no case seen in the genus do all the oculars reach the periproct as the quoted sentence implies.

The South American species, *Arbacia nigra*, may be considered the most progressive of the genus with typically three oculars insert. In ten young specimens a few millimeters in diameter, all the oculars are exsert as in the typical condition of adult *punctulata*. Of adults, in 246 specimens only 1% have all oculars exsert, the typical character for several species, but an extreme arrested variant in *nigra*. Ocular V only is insert in 22% and V, I in 12%. Both of these are arrested variants for *nigra* while they would be progressive variants for most other species of the genus. The typical character of V, I, IV insert (text-fig. 167, p. 149) occurs in 57%. Aberrant variants are unusually frequent in this species, 8%, which is high where a considerable number of specimens were examined. Thirteen of the nineteen variants have V, IV insert, a common variant in the genus, as noted under *spatuligera*. One specimen has oculars I, IV, and one has I, V, III insert. Four of the variants have V, I, IV, III insert, a sequence also noted by Clark (1907, p. 193). These are the only cases of four oculars insert seen in the family; it is a rare sequence in the order, but quite common in the Cidaroida. *Arbacia nigra* with a high percentage of three plates insert is in this character the most progressive species of the genus, and it is of importance that three other characters bear out the same conclusion. The auricles of the perignathic girdle quite commonly meet in an arch (text-fig. 228, p. 193), a progressive character not usual in other species (text-fig. 227, p. 193); also there are more pore-pairs to an ambulacral plate than in other species, and secondary spines are present, all concurrently marking it as the highest species in the genus.

In two specimens of *Coelopleurus floridanus*, all oculars are exsert as in the more primitive Arbacias, and in the young of the more specialized species of the same. The Arbaciidae present quite a limited range of characters in regard to ocular plates. All plates exsert is the most frequent species feature, or three plates may be insert. All other characters found are variants, either arrested, progressive, or aberrant. Of 53 aberrants seen in the family, 40 are cases of oculars V, IV insert; the other thirteen aberrants are scattering (tables, pp. 158, 164).

Of the Camarodonta, which is the last suborder of the Centrechinoida, I have had the opportunity to examine many species and large series of several.

Of the first family, the Temnopleuridae, 400 specimens including 15 species have been studied as listed in the table, p. 159. The Cretaceous *Glyphocyphus radiatus* has very low genitals and oculars, and the latter are all insert in the seven specimens seen. The Recent *Temnopleurus reevesii* shows a strong tendency for ocular I to be insert, and this with other cases indicates that this is the first plate to become insert in this family as in the Echinidae. All the other species have all oculars exsert with rare exception. *Microcyphus maculatus* (139 specimens) in one case has oculars I, V insert, the only case seen in the family, and two aberrants were found, one with ocular IV insert and one with II insert, both very rare occurrences in Echini as a whole. Mr. Agassiz (1873) and Dr. Mortensen (1904, p. 63) note that one or more ocular plates may be insert in species of this family, but in Recent species they are apparently exceptional characters, and, as a whole, the family from present evidence is characterized by oculars all exsert.

In the family of the Echinidae I have had the opportunity to examine a large number of

TEXT-FIGS. 115-117.—Ocular plate arrangement in species of Echinus.

115. *Echinus affinis* Mortensen. Off east coast of United States, 1,022-1,106 fathoms. U. S. Nat. Mus. Coll., 14,851. $\times 3$. All oculars exsert, extra genital pores, ambulacral plates composed of two elements dorsally, and are simple primaries next the ocular. Plates of periproet numerous and very small excepting the suranal opposite genital 3 (pp. 171, 176).

115a. Same species and locality. R. T. J. Coll., 891. $\times 3$. Ambulacral plates of two elements each, extending down to the mid-zone, below which all have three elements (p. 216).

115b. The same. R. T. J. Coll., 892. $\times 3$. No ambulacral plates with two elements each.

116. *Echinus esculentus* Linné. English Channel. Diam. 103 mm. R. T. J. Coll., 723. $\times 2$. All oculars exsert, typical character.

117. The same. Plymouth, England. Diam. 94 mm. R. T. J. Coll., 764. $\times 2$. Ocular I insert, a progressive variant.

specimens, and the characters in regard to ocular plates present a wide range. When oculars become insert, they do so in the sequence I, V, IV, II, III. Rarely V alone is insert, and when this occurs, the character in so far as is an approach to the Echinometridae (table, pp. 160, 161).

Echinus as the type genus of the family is of especial interest. Of *Echinus affinis* Mortensen, 605 specimens were observed in the National Museum. The material was from the Albatross Station 2,094, off the Carolina coast in about 1,000 fathoms depth, and had been identified by Dr. Mortensen. This species is remarkable as regards oculars in that all were exsert without exception (text-fig. 115). This is the only species of Echini studied in which with a large number of observations no variation in this respect was seen. One marked peculiarity of the species, which seems to have been overlooked, is the fact that, while the ambulacral plates up to the mid-zone or further consist of three elements each, dorsally the plates to a greater or less extent may consist of two elements, as shown in text-fig. 115. The two-element plates may be wanting (text-fig. 115b) or they may occur only near the upper end of the ambulacrum, while in other specimens they may extend nearly or quite to the mid-zone (text-fig. 115a).

In *Echinus elegans* and *E. gracilis* all oculars are exsert in the specimens seen.

In *Echinus esculentus* (200 specimens) 97 % have all oculars exsert (text-fig. 116), but in 3 % ocular I is insert (text-fig. 117). This is the ocular that first comes in in this family when one or more oculars are insert. The specimens with I insert, barring one exception, are small or moderate sized, emphasizing the fact elsewhere noted that the incoming of oculars is a matter of relative development, not of age and size of the individual. This species attains a very large size, my largest from Plymouth, England, being 132 mm. in diameter.

Echinus miliaris (129 specimens) has 98 % with oculars all exsert, but in one specimen ocular V is insert, a character unusual for the family, and in two specimens I, V are insert, a normal progressive variant for the species. *Echinus microtuberculatus* (299 specimens) has typically, 96 %, all oculars exsert; but in 2 % ocular I is insert, in 1 % ocular V, and in 0.3 % oculars I, V are insert as progressive variants. Two specimens are aberrant with oculars I, IV insert. Of the species *Echinus melo*, only ten specimens were seen. Of these, 90 % have all oculars exsert, but one specimen, 10 %, has ocular I insert as a progressive variant. A specimen of *Echinus melo* from the Mediterranean, in the Peabody Museum, Salem, Massachusetts, is of exceptional size, the largest sea-urchin I have seen. It measures 168 mm. in diameter and 132 mm. in height, the circumference measuring 532 mm. The largest sea-urchin as far as known is recorded by Messrs. A. Agassiz and Clark (1909), who say that the type of *Sperosoma giganteum* A. Agassiz and Clark measures nearly 320 mm. in diameter. As this form is highly flattened, its cubic contents is proportionately lessened.

Of *Echinus acutus* (127 specimens), in 82 % all oculars are exsert, but in 18 % ocular I is insert, showing that in this character it is much more progressive than the above species. In a superb series sent me by the Plymouth (England) Biological Laboratory, there is great indi-

vidual variation as regards shape, some being depressed spheroidal, others almost conical. The largest specimen measures 145 mm. in diameter and 96 mm. in height.

Echinus angulosus, which is a distinctly southern species, from South Africa (100 specimens), has typically, 54 %, all oculars exsert. In 30 % ocular I is insert as a progressive variant, and in 4 % ocular V alone is insert. In 9 % oculars I, V and in 2 % I, V, IV are insert. One specimen is aberrant with oculars I, IV insert. This species is distinctly more evolved as regards oculars than any northern species of the genus.

Another southern species is *Echinus magellanicus*, from Patagonia and that region. A fine series was studied in the collections of the Museum of Comparative Zoölogy and the National Museum. In the very young, 2.5 to 5 mm. in diameter (36 specimens), the oculars are all exsert in 97 %, but one specimen, the largest of the series, has ocular I reaching the periproct, as in the adult typically. This immature condition of all oculars exsert is directly comparable to the adult character of the northern *Echinus esculentus*. In the younger specimens studied (Plate 3, fig. 14) the oculars are broadly exsert, but I is furthest in, genitals are imperforate, and there is a single madreporic opening in the middle of genital 2; also the suranal plate fills the periproctal area, all as in young *Strongylocentrotus* (text-fig. 131, p. 129). On the peristome the primordial ambulacral plates nearly fill the area, and, as in *Strongylocentrotus* (Plate 3, fig. 11), the primordial plates Ib, IIb, IIIa, IVb, Va have an ambulacral perforation whereas the other plates are imperforate. The largest immature specimen, which has ocular I insert, is 5 mm. in diameter and has four madreporic pores and two periproctal plates in addition to the suranal. Adult *Echinus magellanicus* (164 specimens) has typically, 88 %, ocular I insert (text-fig. 165, p. 149). In 5 % all the oculars are exsert as arrested variants, like the young and the typical character of the northern species of the genus; two of these variants were the largest specimens seen of the species. In 4 % oculars I, V are insert as progressive variants, like the typical character of *Echinus margaritaceus*, and one specimen has oculars I, V, IV, II insert. Two specimens are aberrant variants, one with oculars I, II insert like the typical character in *Gymnechinus*, and one with V, II insert, ocular I being excluded by the fusion of genitals 5, 1, as in text-fig. 146, p. 134. *Echinus magellanicus* has the highest percentage of ocular I only insert of any sea-urchin known. In this species there are ten primordial ambulacral plates in the peristome, as usual, but, as shown by Döderlein (1906), the peristome is otherwise without plates, a very unusual character, seen, however, in some of the *Temnopleuridae* (p. 84).

Echinus margaritaceus, from southern South America and the Antarctic, is a most interesting species. Sixteen specimens were studied, twelve being in the Museum of Comparative Zoölogy, one in de Loriol's collection, and three were kindly loaned me by Dr. Mortensen under the name *Echinus* (*Sterechinus*) *neumayeri*, but they seem referable to this species as a synonym, and therefore are included with it in the tabulation. Out of the sixteen specimens, in nine,

or 56 %, oculars I, V are insert, as the typical species character. As variants, a most extraordinary range of characters is presented for such a limited series of specimens. In one specimen each, the following structural characters are shown: oculars all exsert, I insert, and V insert as arrested variants, and I, V, IV insert, I, V, IV, II, and all insert as progressive variants; one specimen is aberrant with I, V, II insert, a feature rather common in this family. The three specimens sent me by Dr. Mortensen as above noted are two with I, V insert and one with I, V, II insert. The range of normal arrested and progressive variants with the typical character covered by the few specimens seen of this species, is greater than has been found in any other species in the family. Kochler (1906) says of this species that in most cases two oculars reach the periproct, and he shows a wide range of characters in his excellent figures. In his figure 30*d* oculars I, II are insert, the same as I found in an aberrant *E. magellanicus*.

According to de Loriol (1883), in *Echinus verruculatus* Lütken, from Mauritius, two oculars are insert, the bivium as shown in his figure. Mortensen (1909) shows in *Sterechinus antarcticus* Koehler and *S. diadema* (Studer) from the Antarctic that three, four, or five ocular plates may be insert. His table (1909, p. 75) shows some aberrant arrangements of oculars that I have not seen in any Echini. All the evidence goes to show that the northern species of *Echinus* have all oculars exsert, or occasionally one or two plates insert as progressive variants. On the other hand, the far southern species have one, two, or more to all plates insert as a frequent variant or as a typical species character (table, p. 160).

The genus *Gymnechinus* is closely allied to *Echinus*, and two species have been studied which present extraordinary characters. Of *Gymnechinus robillardi* I have studied nine specimens, seven of which are in de Loriol's collection, in the Geneva Museum. Eight of these, or 89 %, have oculars I, II insert and V, IV, III exsert (text-fig. 179, p. 165). One specimen in de Loriol's collection has ocular I only insert as an arrested variant. The essential structure of the apical disc in this species is similar to that of the next. Of *Gymnechinus pulchellus* Dr. Mortensen most generously sent me ten specimens from the Gulf of Siam and Singapore. The periproct is quite eccentric (text-figs. 177, 178, p. 165), so that a line drawn through ocular III and genital 5 barely cuts the periproct; the genitals are much larger on the left than on the right of this line. In fourteen specimens seen, oculars I, II are insert and V, IV, III exsert in all cases, and Dr. Mortensen writes me that this is always the case in this species. These are the only species of Echini seen (except *Strongylocentrotus gibbosus*) in which an aberrant arrangement of ocular plates is a typical species character. When two oculars reach the periproct, it is typically I and V in all other Echini in over 99 % of the 35,184 cases observed. For oculars I, II to be insert is a relatively rare character seen in only thirty-four specimens other than *Gymnechinus*, and all of these are in the families of the Echinidae or Strongylocentrotidae. Another extraordinary character common in these species of *Gymnechinus* is for genital 3 or 4 to be exsert or excluded from the periproct (text-figs. 177-179, p. 165), as discussed under consideration of genital plates.

The five species of *Toxopneustes* all have typically oculars I, V insert, but there is considerable variation shown. *Toxopneustes maculatus* (five specimens) has 80% with oculars I, V insert and 20% with I only insert as an arrested variant. *Toxopneustes pileolus* in 38 specimens has 92% with oculars I, V insert and 8% as arrested variants with I only insert. *Toxopneustes semituberculatus* in 25 specimens has 96% with oculars I, V insert and 4% arrested with I only insert, thus being more progressive than *pileolus*. The next two species show arrested variants, but also progressive variants, and in an increasing degree.

Toxopneustes variegatus, from the West Indies and Florida (1,043 specimens, all adults), has as the species character 90% with oculars I, V insert (text-fig. 184, p. 165). As arrested variants, 1% have ocular I only insert, one specimen has V only insert. As progressive variants, 8% have oculars I, V, IV insert and 0.2% have I, V, IV, II insert; 0.8% are aberrant variants. Of the eight aberrant variants, two have oculars I, IV insert, V being excluded by the fusion of genitals 4, 5 as in text-fig. 144, p. 134; one has oculars V, II insert, I being excluded by the fusion of genitals 5, 1 as in text-fig. 146, p. 134; and five specimens have oculars I, V, II insert as in text-fig. 145, p. 134, a right-handed equivalent of the typical progressive variant I, V, IV. The comparison of this species with the next, which is a close ally, is interesting.

Toxopneustes atlanticus (A. Agassiz), from Bermuda, has been considered a synonym of *T. variegatus* (Lamarek), but it is here considered a distinct species.¹ In *Toxopneustes atlanticus* the species character of oculars I, V insert is taken on early, as usual, but the number of progressive variants typical of adults is taken on at a later stage than in any other sea-urchin studied. I have therefore divided the material into three series: the smallest, 35 to 45 mm. in diameter, which is still developing; a larger series, 45 to 60 mm., which is developed as regards ocular arrangement; and a third series, 60 to 77 mm. in diameter, which includes the largest specimens seen (table, p. 161). In the smallest series, 35 to 45 mm. in diameter (587 specimens), 81% have oculars I, V insert, a much higher percent than in adults. Of arrested variants 0.9% have I only insert, a small proportion, showing that it is fully developed in this respect. One specimen, 0.2%, has ocular V only insert. As progressive variants, 16% have I, V, IV insert, about half the proportion of adults, and 0.3% have I, V, IV, II insert, again about half the proportion seen in large specimens. There are in this smallest series twelve aberrant variants, 2%. Of these, one specimen has oculars I, IV insert, four have V, II, six have I, V, II, and one has V, IV, II insert.

¹ *Toxopneustes atlanticus* was described as *Leptechinus atlanticus* by Mr. Agassiz (1863) on the basis of its slender spines. The spines are long, slender, soft to the touch, and typically of deep violet color, although light violet or green spines occasionally occur. In *T. variegatus* the spines are stout, rigid, and usually gray or green. The peristomal plates are smaller than in *variegatus*; the color of the test is violet, not green or gray mottled as in *variegatus*. The arrangement of ocular plates as regards insertness differs very much from *variegatus*, progressive variants being more numerous as here shown. These comparative characters are constant in the large series of each species observed. While these two species are very close, it seems reasonable to consider *atlanticus* as distinct.

TEXT-FIGS. 118-122.—Ocular plate arrangement of *Toxopneustes atlanticus* (A. Agassiz). Bermuda. All figures $\times 2.7$.
 118. Diam. 51 mm. R. T. J. Coll., 873. All oculars exsert, extreme arrested variant.
 119. Diam. 77 mm. R. T. J. Coll., 893. Ocular I only insert, arrested variant, the largest specimen of the species seen.
 120. Diam. 70 mm. R. T. J. Coll., 875. Oculars I, V insert, the typical character.
 121. Diam. 65 mm. R. T. J. Coll., 876. Oculars I, V, IV insert, a common progressive variant.
 122. Diam. 59 mm. R. T. J. Coll., 877. Oculars I, V, IV, II insert, extreme progressive variant (p. 176).

In the next larger series of *Toxopneustes atlanticus*, 45 to 60 mm. in diameter (1,463 specimens), 67% have oculars I, V insert, a wide departure from *variegatus*. Of arrested variants (one specimen) 0.1% have all oculars exsert (text-fig. 118), 0.5% ocular I only insert, and 0.1% have V only insert. As progressive variants, 28% have oculars I, V, IV insert and 1.2% have I, V, IV, II insert (text-fig. 122), the extreme variation of the species as far as known. Aberrant variants in this size are frequent, 36 specimens, or 2.5%. Of these, ten specimens have oculars V, II insert, fourteen have I, V, II, eleven V, IV, II, and one I, V, IV, III, this last a rare variant in the family.

In the largest series studied, 60 to 77 mm. in diameter (593 specimens), 68% have the typical character of oculars I, V insert (text-fig. 120). Of arrested variants, 0.7% have ocular I alone insert, one of these (text-fig. 119) being the largest specimen seen in the species. As progressive variants, 29% have oculars I, V, IV insert and 0.7% I, V, IV, II insert. The aberrant variants in this largest size are eleven, 1.8%; of these, four have oculars V, II insert, five I, V, II, one V, IV, II, and one I, V, III insert, this last an extremely rare variant in Echini. Looking at the tabulation as a whole (p. 161), it is seen in this species that the series 35 to 45 mm. in diameter is not fully developed as shown by the percentages of progressive variants, and aberrant variants are not quite so frequent as in the next larger size. In the series 45 to 60 mm. in diameter the range of percentages is practically the same as in the largest size, but

there are slightly more of I, V, IV, II insert as an extreme progressive variant and also more aberrants. The largest series of 60 to 77 mm. in diameter, has about the same proportion of arrested variants as in the two smaller sizes. Again, its progressive variants are practically of the same frequency as in the next smaller series, demonstrating what I have found all through Echini, that the incoming of oculars is a matter of individual development and not a matter of age or size. Of aberrants in this species, 59 were found in the 2,643 specimens tabulated. Of these all of the 31 specimens having V, II or V, IV, II insert, also have genitals 5, 1 fused, which mechanically prevented ocular I from reaching the periproct, as in text-figs. 146 and 148, p. 134. The one specimen with oculars I, IV insert has genitals 4, 5 fused which mechanically prevented ocular V from reaching the periproct, as in text-fig. 144, p. 134. This accounts for a trifle over half of the 59 aberrant variants seen in the species (p. 164). Of the remaining 27 aberrants, 25 are cases of I, V, II insert, as in text-fig. 145, which is a right-handed equivalent of I, V, IV, and one specimen is a case of I, V, IV, III insert, which is considered as reversionary to the character common in the Cidaroida, as in text-fig. 69, p. 98. There is therefore only one variant, which has oculars I, V, III insert, that could in any sense be considered as sporadic, a small number in so large a series. This species shows almost exactly the same range of characters as *Toxopneustes variegatus*, but is markedly more progressive than that species. The immature series as above described goes far toward bridging the gap between the two, and a still younger would probably do so completely. In this regard it may be noted that a small lot of 37 specimens of 30 to 35 mm. in diameter, and not listed in the tables, has 92% with oculars I, V insert, no arrested variants, but 5.4% with I, V, IV insert. This shows that at this age it is fully developed as regards the bivium, but has relatively few of the progressive variants, less even than adult *T. variegatus*.

The genus *Tripneustes* presents interesting characters with a considerable range. Of *Tripneustes depressus* only 16 specimens were seen, but typically, 75% oculars I, V are insert; 6% are arrested with I only insert; and 19% are progressive variants with I, V, IV insert. In *Tripneustes variegatus* (72 specimens) oculars I, V are insert in 68% as the species character. Of arrested variants, 7% have I only, and one specimen has V only insert. Progressive variants are more common, 8% with I, V, IV and 11% with I, V, IV, II insert. Three specimens are aberrant, two with I, II insert as in *Gymnechinus pulchellus*, and one with V, II insert as in text-fig. 146, p. 134.

Tripneustes esculentus is an interesting species on account of its range of characters in ocular plates, both within a locality and in two widely separated areas (table, p. 161). In 193 specimens from Bermuda 61% have oculars I, V insert as the typical character for that locality. In 2% ocular I only is insert as an arrested variant (text-fig. 123). It is noteworthy that the three specimens showing this character are large individuals, the one figured being the largest seen in the species. Of progressive variants, 35% have oculars I, V, IV insert, 2% I, V, IV, II,

and 0.5% all oculars insert. Two specimens are aberrant variants, one with I, V, II and one with V, IV, II insert (text-fig. 196, p. 169); as genitals 5, 1 are fused, this may be considered

TEXT-FIGS. 123-127.—Ocular plate arrangement in *Tripneustes esculentus* (Leske). All figures $\times 2.7$.

123. Bermuda. Diam. 145 mm. R. T. J. Coll., 896. Ocular I only insert, an extreme arrested variant, but the largest specimen seen in the species.

124. Nassau, Bahamas. Diam. 100 mm. R. T. J. Coll., 675. Oculars I, V insert, an arrested variant for the West Indies.

125. Nassau, Bahamas. Diam. 95 mm. R. T. J. Coll., 677. Oculars I, V, IV insert, the typical character for the West Indies.

126. Nassau, Bahamas. Diam. 81 mm. R. T. J. Coll., 653. Oculars I, V, IV, II insert, a progressive variant (p. 94).

127. Bahamas. Diam. 95 mm. R. T. J. Coll., 676. All oculars insert, an extreme progressive variant.

an incomplete I, V, IV, II. The species is abundant in Bermuda and attains a large size. The range of variation of Bermuda specimens is similar to that of the southern form, but the percentages are radically different.

Tripneustes esculentus from the West Indies and Florida as regards oculars is much more progressive than the Bermuda form. I have divided the specimens into an immature develop-

ing and a developed series. In the developing series of 55 specimens, varying from 19 to 50 mm. in diameter, 76% have the bivium insert, quite near to the character of adults from Bermuda. In 9% ocular I only is insert. Of progressive variants, 13% have oculars I, V, IV insert. This is much below the percentage of adults, in which I, V, IV insert is the character in this region. One aberrant has oculars I, V, II insert.

In the developed series of 50 to 127 mm. diameter from the West Indies and Florida (455 specimens), in 38% oculars I, V, IV are insert as the typical character (text-fig. 125). This is the only species of the family in which I, V, IV has been found as a dominant character, although it is a frequent variant in many species. As arrested variants two specimens, large adults, have V only insert. In 36% oculars I, V are insert (text-fig. 124). This is an arrested variant for the southern, while it is the typical character for the Bermuda form of the species. As progressive variants 18% have oculars I, V, IV, II insert (text-fig. 126). This variant is important as it includes the bivium and posterior pair of the trivium, thus marking the bilateral symmetry in regular Echini as indicated by the incoming of ocular plates. In 1% all the oculars are insert (text-fig. 127). The aberrant variants of the southern form of *Tripneustes esculentus* are rather frequent, 6%. Of the 27 aberrants, one has oculars I, IV insert, as in text-fig. 144, and 24 have oculars I, V, II insert, which is the bivium and right posterior plate of the trivium instead of the left as usual. One specimen has V, IV, II insert, in which ocular I is excluded by the fusion of genitals 5, 1 (text-fig. 196); and one has I, V, IV, III insert, a rare variant in the order but common in the Cidaroida. The difference in *Tripneustes esculentus* from Bermuda and the West Indian area appears to be marked only in the arrangement of the ocular plates, no other distinction being observed. It is the same difference noted in several other species where series from widely separated areas are tabulated. It shows differential characters developing, not distinguishable in a single specimen, but obvious in a large series. Such may be considered as incipient species in the process of making. In the total number of 703 specimens tabulated, it is interesting to note that of 30 aberrants, 26 are cases of I, V, II insert, and of the other four cases in three (p. 164) the aberration was due to the fusion of two genitals mechanically shutting out an ocular.

Of *Evechinus chloroticus* (20 specimens) in 90% oculars I, V are insert, one specimen is a progressive variant with I, V, IV insert, and one specimen is aberrant with I, IV insert.

Considering the family Echinidae as a whole, many species of the genus Echinus have all oculars exsert as a character. One species, *Echinus magellanicus*, has ocular I only insert, and many species in the family have typically oculars I, V insert. Only one species, *Tripneustes esculentus*, has typically oculars I, V, IV insert and this only in its southern localities. Four or five plates insert are rare in the family except in the southern form of *Tripneustes esculentus* and the Antarctic species of Echinus (table, pp. 160, 161).

The Strongylocentrotidae includes genera in which the test is circular in outline, with

more than three elements in each ambulacral plate and other characters as discussed in the section on Systematic Classification. Of this family *Pseudoboletia indiana* (ten specimens) has in all the bivium insert. *Sphaerechinus pulcherrimus* (48 specimens) has 98% with oculars I, V insert and 2% with I only insert as an arrested variant. *Sphaerechinus granularis* (291 specimens) has typically, 89%, oculars I, V insert. Two specimens are arrested variants with I only insert; three are progressive variants with I, V, IV and three with I, V, IV, II insert. It is rather remarkable that this wide range of characters should be represented by so few specimens, but the same limited occurrence of a typical variation occurs in many species. The aberrant variants of *Sphaerechinus granularis* are relatively very numerous, 9%; two of these have oculars V, IV insert, but the 23 others all have oculars I, V, II insert, a case of the bivium and right hand instead of left hand of the trivium as usual. The frequency of this character suggests that some species might typically have I, V, II insert, but such is unknown (pp. 93, 141).

Strongylocentrotus, on account of the number of pore-pairs and plate elements in its compound ambulacral plates, is the most specialized genus of the family in this important structure. It belongs with this family rather than with the Echinometridae (in which it has been placed) on account of the circular, not oval form, and because the oculars become insert in the sequence I, V, not V, I as in that family. I have been fortunate in studying a good series of most of the species and their mutual relations are very interesting (table, p. 162).

Strongylocentrotus lividus as regards ocular arrangement is the most primitive species of the genus, as it is also as regards the number of elements entering into the compound ambulacral plates. Of this species I have examined 1,163 specimens, mostly from the Naples Station. Of these, as the species character, 75% have all the oculars exsert (text-fig. 128). This includes the largest specimens seen (68.5 mm.) as well as smaller individuals. All oculars exsert is also the character of very young specimens of *S. dröbachiensis* (text-fig. 131). In *lividus* 17% ocular I is insert as a progressive variant (text-figs. 129, 129a). This character is like the typical feature of young *S. dröbachiensis* when 4 to 5 mm. in diameter (text-fig. 133) and also like arrested variants of the same species (text-fig. 136). In *lividus* 2% have ocular V alone insert. This is a relatively rare character in the Echinidae, but is more frequent in some species of the Strongylocentrotidae, and in the Echinometridae it is the dominant character when only one ocular reaches the periproct. In *lividus* 4% have oculars I, V insert (text-fig. 130), which is a progressive variant for the species, but is the dominant character of *S. dröbachiensis* and most species of the genus. One specimen only, 0.1%, has oculars I, V, IV insert. This specimen has ocular IV fused with genital 3, like the ocular IV fused with genital 4 in text-fig. 143, p. 134. The character of oculars I, V, IV insert which is an extreme and very rare progressive variant in *lividus* is a relatively common progressive variant and frequent in an increasing degree in the higher species of the genus, as shown in the table. The progressive variants in *S. lividus* occur in small or medium sized individuals, and only

occasionally in large ones, demonstrating as elsewhere claimed that the incoming of oculars is a matter of individual variation and not of age. There are 15 aberrants, 1%; of these one specimen has ocular III alone insert, a very rare variant in Echini, seen in only two other specimens. Five specimens have ocular II alone insert, also a rare variant. Four specimens have I, IV insert, two have I, II, and three have V, II insert. These are aberrants that occur in species of the Echinidae and especially *Strongylocentrotus dröbachiensis*, as shown in the table of aberrants. A large number of specimens of *lividus* were received after the diagram (text-fig. 176) was drawn and these altered the percentages considerably from what is there shown. Mr. Agassiz (1873, p. 446) said of this species, that one ocular reaches the periproct in medium sized specimens, and two oculars in large specimens. He did not mention all oculars exsert, which in those I have seen is the dominant character; also two oculars insert is quite as frequent in small specimens as it is in larger ones. *Strongylocentrotus lividus* is exceptionally interesting as in its dominant character and progressive variants it presents features in arrangement of oculars precisely like those seen in the development of *S. dröbachiensis* (text-figs. 131-134); also its typical character and progressive variants are directly comparable to the arrested variants or typical character and progressive variants of adult *dröbachiensis* (text-figs. 135-138, p. 132).

TEXT-FIGS. 128-130.—Ocular plate arrangement in *Strongylocentrotus lividus* (Lamarck). Naples, Italy. All figures $\times 4.5$.

128. Diam. 65 mm. R. T. J. Coll., 697. All oculars exsert, the typical character. Compare text-figs. 132, 135.

129. Diam. 37 mm. R. T. J. Coll., 765. Ocular I insert, a progressive variant. Compare text-figs. 133, 136.

129a. Diam. 24 mm. R. T. J. Coll., 698. Ocular I insert.

130. Diam. 53 mm. R. T. J. Coll., 766. Oculars I, V insert, a progressive variant. Compare text-figs. 134, 137.

Strongylocentrotus albus from the west coast of South America is an interesting species. In 60 specimens, 53% have all oculars exsert like the typical character in *S. lividus*. A con-

siderable range is shown, however, and as all exsert is the typical feature, variants are therefore all progressive. In 2% ocular I is insert, in 5% V, in 25% I, V, and in 2% I, V, IV are insert. Aberrant variants are frequent, 13%. Of these, one specimen has ocular III alone insert, a variant seen in only two other sea-urchins, four specimens have V, III insert, a unique variation, two have V, IV, III insert, which is the dominant character of *Strongylocentrotus gibbosus* (text-fig. 156, p. 145), and one specimen has oculars I, V, IV, III insert. It is striking that so many and such peculiar aberrant variants occur in this species, and the same is true of other species from the west coast of South America as noted (table, p. 164). Mr. Agassiz (1873, p. 438) says of this species that all oculars except one are excluded from the periproct, but I find that there is much variation and that all oculars exsert is the specific character.

***Strongylocentrotus fragilis* sp. nov.**

This new species is striking for its size and the extreme thinness of the test. In shape it is strongly depressed, almost flat ventrally, the ambitus almost coinciding with the base. The color is reddish claret; young specimens are orange red; spines are short, 10 to 20 mm. long, light colored. Ambulacral plates have five elements each. Interambulacral plates ventrally have a row of primary tubercles up to six in number to each plate. At and above the ambitus there is a vertical series of one prominent primary tubercle to a plate in both interambulacral and ambulacral areas. Secondary and miliary tubercles are very small. Pedicellariae are similar to those of *S. dröbachiensis*. In the type the diameter of the apical disc through III, 5 is 18 mm.; of the peristome in the same plane 27 mm. The test is very thin and correspondingly fragile, 0.6 mm. thick at the mid-zone. Of seven specimens in my collection all are of about the same size, but that selected as the type (R. T. J. Coll., 838) measures 94 mm. in diameter at the ambitus and 44 mm. in height. The specimens were collected at Catalina Island, off the southern California coast, and were sent me by Ward's Natural Science Establishment at Rochester, New York. A number of specimens are in the collection of the United States National Museum, dredged off the coast of southern California and Oregon in depths of 124 to 339 fathoms. These are smaller, about half grown, and are included in the tabulation of ocular plates. Of this species (55 specimens) 56% have oculars I, V insert as the typical character. Of arrested variants 13% have all the oculars exsert, 29% have I only insert, and 2% have V only insert. There are no progressive variants or aberrants. Photographic figures, in dorsal and side view of the holotype of this species will appear in Part 4 of Agassiz and Clark's Hawaiian and other Pacific Echini, Memoirs of the Museum of Comparative Zoölogy, Vol. 34; Plate 113, figs. 3, 4.

Of *Strongylocentrotus mexicanus* only six specimens were seen; five have oculars I, V and one has V only insert. In *Strongylocentrotus tuberculatus* (39 specimens) 92% have oculars I,

V insert as the character, one specimen is arrested with ocular I only insert, one is progressive with oculars I, V, IV and one aberrant with I, IV insert. Of *Strongylocentrotus depressus* in the few specimens seen all have oculars I, V insert.

In such a study as here undertaken it is desirable to work out as fully as possible the development and variation of some one species. I have attempted to do this with *Strongylocentrotus dröbachiensis* as a good representative type and the only one of which I had the opportunity to accumulate a very large number of observations. A study was made of the development and variation in many localities of 33,000 specimens. In handling material and making observations in large numbers one is likely to make an occasional mistake, so I went over most of the material a second time when a few variants were found that escaped notice on the first count. The character of this species is strongly to have oculars I, V insert, but there is considerable variation in all localities and also there is considerable difference in the range of variation between localities. This is set forth in the text and in tabular form on p. 143. The aberrant variants of this species are all given together in the table of aberrants of the Centrechinoida, p. 164.

TEXT-FIGS. 131-134.—Development of ocular plate arrangement in *Strongylocentrotus dröbachiensis* (O. F. Müller).

131. Diam. 1.2 mm. Adapted from Lovén, 1892, Plate 4, fig. 27. $\times$ about 22. All oculars broadly exsert; one large madreporic pore only; the suranal plate fills the periproct (p. 172).

132. Salem Harbor, Massachusetts. Diam. 4 mm. R. T. J. Coll., 767. $\times$ 22. All oculars exsert.

133. York Harbor, Maine. Diam. 4.5 mm. R. T. J. Coll., 679. $\times$ 22. Ocular I insert (text-fig. 181, p. 165).

134. York Harbor, Maine. Diam. 7 mm. R. T. J. Coll., 680. $\times$ 21. Oculars I, V insert.

In text-figures 132 to 134 the madreporic pores progressively increase in number and the suranal plate proportionately decreases in size; no genital pores exist (pp. 170, 176).

Taking up the development first, Lovén (1892) showed that in a very young specimen all the oculars are strongly exsert (text-fig. 131); a suranal plate fills the periproct; genital pores do not exist, and the madreporite has one large madreporic pore instead of many as later. An older specimen (text-fig. 132) has still all the oculars exsert, although ocular I approaches nearest to the periproct and it compares favorably with the adult character of *Strongylocentrotus*

lividus (text-fig. 128). The suranal plate does not fill the periproct as in the earlier stage after Lovén, but it lies opposite genital 3, as in *Salenia* (Plate 4, fig. 1). A few secondary periproctal plates have developed as seen also in the next two figures. No genital pores have appeared, but instead of a single pore in the madreporite, as in text-fig. 131, there are several pores and these increase in later stages (text-figs. 133, 134). At a later stage (text-fig. 133) ocular I has entered the periproct, but all other oculars are exsert. This stage may fairly be compared with progressive variants of *S. lividus* (text-figs. 129, 129a) that also have ocular I insert. In a still later stage (text-fig. 134) ocular I is fully insert and V is narrowly insert. This specimen, though only 7 mm. in diameter, has taken on the adult character of the bivium insert. In its detail it can be aptly compared with the extreme progressive variant of *S. lividus* (text-fig. 130). The specimen from which text-fig. 132 was drawn is 4 mm. in diameter, while that from which text-fig. 134 was drawn is 7 mm. in diameter, not far from twice as large, yet the apical disc of text-fig. 134 is only a little larger than that of text-fig. 132. This shows, what was earlier stated (p. 87), that the apical disc proportionally does not keep pace with the size of the test during growth but with development becomes relatively smaller. This relative change is more marked in early than in later stages of growth in which the relative reduction in this species is very slight.

In order to test the age at which characters are taken on and to see what might be the range of variation at different ages, a large series of young and adult specimens was collected. The youngest series of 2.5 to 5 mm. in diameter came from several localities on the Maine and Massachusetts coasts, but were mostly collected on Chelsea Beach, Massachusetts, by Mr. J. Henry Blake, who kindly gave them to me. Succeeding this age, a series of specimens was collected at Dumpling Islands, North Haven, Maine. This locality is a favorable spot as specimens are abundant and attain an exceptionally large size, so that the range of size and presumably age is quite full. The specimens were collected at spring tides, when with exceptionally low water they could be easily picked off the rocks. All were taken from within a radius of about two hundred feet and all were from as uniform conditions as possible. The specimens were measured with a steel caliper rule; 11,500 specimens from this locality were thus measured and observed, and are divided into two series: what I call a developing series under 30 mm. in diameter, and a developed series over 30 mm. in diameter. This is based on the fact that when over 30 mm., the typical adult character for that locality was established by the percentage having the bivium insert. Younger series of specimens in a progressively increasing degree have less of the full character developed and a greater percentage of individuals of immature character as shown in the table, p. 142.

Taking up the developing series, it is safe to assume that at a very early stage all specimens would have all oculars exsert, as in text-fig. 131. Specimens (51) 2.5 to 4 mm. in diameter, the youngest I found, have 29% with oculars all exsert and 71% with I only insert. Of these latter, many specimens had the ocular only barely reaching the periproct, indicating that it

had but just taken on this position. Specimens (82) 4 to 5 mm. in diameter have 4 % with all oculars exsert and 96 % with ocular I only insert. All the specimens up to this age lack genital pores. Specimens (800) 5 to 10 mm. in diameter have 0.1 % with all oculars exsert, 46 % with I only insert, and 52 % have taken on the species character of oculars I, V insert. This shows a very rapid development, for while no specimens under 5 mm. have the bivium insert, more than half have it insert between 5 and 10 mm. While in specimens under 5 mm. all genitals are imperforate, of those between 5 and 10 mm. only 128 out of 800 have all genitals imperforate. In addition, however, 44 specimens were noted in which only part of the genitals were perforate (p. 170). While in this series there are no regular progressive variants, there is 1 % of aberrant variants, the usual number for any age in this species. As the aberrants are all grouped together in one tabulation, it is desirable in the series to give the details, especially in these younger stages. In this 5 to 10 mm. series the aberrants are: one specimen with oculars I, II insert, four with I, IV, and five with I, V, II insert, these last being the only cases of three oculars insert found of this age. One specimen has oculars I, V, IV, III insert and II exsert (text-fig. 149). This is of interest as having four plates insert at this very early age and is an extremely rare aberrant variant for the species, since only two cases have been found in the whole 33,000 examined.

The next older series of 10 to 15 mm. in diameter (2,000 specimens) has progressed markedly. No specimens have all oculars exsert, 19 % have I only insert, and 80 % have I, V insert. The progressive variants here appear and 0.3 % have oculars I, V, IV insert. Only six specimens of this age had all the genital pores wanting, and no larger individuals were seen lacking all the pores. This stage is much more evolved than the next smaller series. Of aberrants the number is 1 % as usual. Two specimens have ocular IV only insert, a very rare variant; four have oculars I, IV, and six have I, II insert. Fifteen specimens have oculars I, V, II insert, a number much exceeding those that have I, V, IV insert at this stage. This is of interest as showing in these early stages a preponderance of oculars I, V, II insert, whereas in the species as a whole, when three oculars reach the periproct, oculars I, V, IV insert preponderate over I, V, II.

Passing to the next size, 15 to 20 mm. in diameter (1,400 specimens), only 7 % have ocular I alone insert; 92 % have I, V insert, a fairly close approach to the adult percentage; and 0.4 % have oculars I, V, IV insert, relatively a little more than in the earlier stage. The aberrants are the usual 1 %. Of these, one specimen has oculars I, II insert, one has V, IV, and one V, II insert; six specimens have I, V, II insert, this number still preponderating somewhat over the proportion of specimens with oculars I, V, IV insert at this stage in development.

The next size, 20 to 30 mm. in diameter (1,250 specimens), is the last of the developing series and makes a close approach to the adult condition. Only 5 % have ocular I only insert, 93 % have I, V, 1 % have oculars I, V, IV, and 0.1 % have oculars I, V, IV, II, insert. This

last is a normal extreme progressive variant for the species, rare as a whole, and the only one found at Dumpling Islands, yet taken on in this relatively youthful specimen. It emphasizes the fact which I have found elsewhere that progressive characters are taken on early in life, and are a matter of individual development and not of age. While the percentage of I only insert is higher than the adult character for this locality, the progressive variant I, V, IV is practically of the same percentage as in adults of the locality. The aberrant variants are

TEXT-FIGS. 135-139a.—Normal ocular plate arrangement in *Strongylocentrotus dröbachiensis* (O. F. Müller). All figures $\times 3$.

135. Frenchman's Bay, Maine. Diam. 33 mm. R. T. J. Coll., 805. All oculars exsert, a unique arrested variant for this species; genitalia 5 and 1 are split by secondary sutures.

136. Frenchman's Bay, Maine. Diam. 40 mm. R. T. J. Coll., 663. Ocular I only insert, a common arrested variant.

137. Nahant, Massachusetts. Diam. 66 mm. R. T. J. Coll., 664. Oculars I, V insert, the typical character of the species.

138. Nahant, Massachusetts. Diam. 37 mm. R. T. J. Coll., 665. Oculars I, V, IV insert, a common progressive variant.

139. York Harbor, Maine. Diam. 28 mm. R. T. J. Coll., 678. Oculars I, V, IV, II insert, a rare progressive variant.

139a. Massachusetts Bay. Diam. 55 mm. R. T. J. Coll., 666. Oculars I, V, IV, II insert as in last figure, a rare progressive variant.

1 % as usual. Of these, one specimen has ocular II only insert, a very rare variant, seen also in one specimen from Frenchman's Bay, but otherwise in only six other sea-urchins, namely in *Strongylocentrotus lividus* and a *Microcyphus maculatus*. Three specimens have oculars I, IV, one V, IV, two V, II, and eight I, V, II insert.

Before considering the developed series from Dumpling Islands, the variation of the species as a whole may be briefly stated. Omitting the developing series as above described, 27,417 specimens have been examined from various localities. Of these, the oculars I, V are insert in 25,766 specimens, 94 %, as a strong species character (text-fig. 137). As an arrested variant only one specimen, 0.004 %, has all oculars exsert (text-fig. 135), as in the young. It is rather remarkable that this variant should be so very rare, as it is the character in two species of the genus. The arrested variant of ocular I insert is rather common, existing in 746 specimens, or 3 % (text-fig. 136). When one plate alone is insert in development or as an arrested variant, it is almost always ocular I, for while in the total recorded in this species 1,758 cases of ocular I insert occur, there are only eleven cases of ocular V alone insert and these all occur in adults, as shown in the table. As progressive variants, 545 specimens, or 2 % have oculars I, V, IV insert (text-fig. 138). Very rarely, in eight specimens, or 0.03 %, oculars I, V, IV, II are insert (text-figs. 139, 139a). This is the extreme range of regular variants found in the species. Of adults there are 340 aberrants, or 1.2 %.

The aberrant variants in the species reach 1.2 % and, as shown in the table of aberrants (p. 164), cover a wide range of characters, but more than one half of the total are cases of I, V, II insert. The principal aberrant variants are shown in text-figs. 140 to 149, which figures also serve to show the principal aberrant variants of the order Centrechinoida. Taking up the aberrant variants of *Strongylocentrotus dröbachiensis*, and here including the whole lot of 33,000 specimens, both young and adult, we find that very rarely ocular IV alone may be insert (text-fig. 140); this was found in only three cases, while still more rarely (two cases) ocular II alone was insert. In no case was III alone insert. Oculars I, II alone are occasionally insert (29 cases) (text-fig. 141). This character is typical of *Gymnechinus pulchellus* (text-figs. 177, 178). As a left-handed equivalent of this last, oculars V, IV alone may be insert, 33 cases (text-fig. 142). This character is more frequent in the Arbaciidae, as there noted. An ocular occasionally fuses with a genital (text-fig. 143). This has been found in 103 cases and may occur between any of the oculars with either of its adjacent genitals. Oculars I, IV may be insert (text-fig. 144). In the great majority of the 81 cases of this aberrant seen in this species, genitals 4, 5 are fused as in the figure, mechanically shutting out ocular V, so that it may reasonably be considered an imperfect I, V, IV insert. Oculars V, II may be insert (text-fig. 146), and in all the 34 cases of this variant seen genitals 5, 1 are fused, mechanically shutting out ocular I, so that this variation may be considered an incomplete I, V, II insert. Oculars I, V, II may be insert, 215 cases (text-fig. 145), and this is the commonest aberrant variant found in the species

TEXT-FIGS. 140-149.—Principal aberrant variants in ocular plate arrangement of *Strongylocentrotus dröbachiensis* (O. F. Müller) (see pp. 93, 94, 164).

140. Calderwood Island, Maine. Diam. 32 mm. R. T. J. Coll., 878. $\times 3$. Ocular IV only insert, a rare variant.

141. Dumpling Islands, Maine. Diam. 64 mm. R. T. J. Coll., 849. $\times 3$. Oculars I, II insert; compare *Gymnechinus*, text-figs. 177-179, p. 165.

142. Dumpling Islands, Maine. Diam. 60 mm. R. T. J. Coll., 850. $\times 3$. Oculars V, IV insert, a left-handed equivalent of text-fig. 141. Madreporic pores in genitals 2 and 1 (p. 172).

143. Dumpling Islands, Maine. Diam. 42 mm. R. T. J. Coll., 867. $\times 3$. Oculars I, V, IV insert, but ocular IV and genital 4 are fused (p. 168).

144. Dumpling Islands, Maine. Diam. 47 mm. R. T. J. Coll., 852. $\times 3$. Oculars I, IV insert, an incomplete I, V, IV, due to the exclusion of V by the fusion of genitals 4, 5 (p. 167).

145. Dumpling Islands, Maine. Diam. 56 mm. R. T. J. Coll., 851. $\times 3$. Oculars I, V, II insert, the commonest aberrant variant, a right-handed equivalent of the normal progressive variant, I, V, IV insert (pp. 93, 141).

146. Dumpling Islands, Maine. Diam. 58 mm. R. T. J. Coll., 853. $\times 3$. Oculars V, II insert, an incomplete I, V, II, due to the exclusion of ocular I by the fusion of genitals 5, 1. Madreporic pores are in genital 2 and ocular III (p. 172).

147. Dumpling Islands, Maine. Diam. 54 mm. R. T. J. Coll., 854. $\times 3$. Oculars I, IV, II insert, an incomplete I, V, IV, II, due to the exclusion of ocular V by the fusion of genitals 4, 5; very rare variant. Ocular III is opposite genital 2 only, not at the junction of genitals 2 and 3, as usual (p. 167).

148. Calderwood Island, Maine. Diam. 50 mm. R. T. J. Coll., 855. $\times 3$. Oculars V, IV, II insert, an incomplete I, V, IV, II, as in text-fig. 147, but due to the exclusion of ocular I by the fusion of genitals 5, 1, a very rare variant (p. 167).

149. Dumpling Islands, Maine. Diam. 9.5 mm. R. T. J. Coll., 856. $\times 12$. Oculars I, V, IV, III insert, a very rare variant. Genitals 3 and 4 split by secondary sutures (compare text-fig. 69, p. 98).

and family. It is a right-handed development of three plates insert, which is usually expressed as I, V, IV insert. One case of I, IV, II (text-fig. 147) and two of V, IV, II insert (text-fig. 148) were found, both very rare variants; in these an ocular of the bivium is mechanically shut out by the fusion of the adjacent genitals. In two cases oculars I, V, IV, III are insert (text-fig. 149), and these were the only cases found in which ocular III entered the periproct in this species.

From the above it is seen that in the 33,000 specimens there are 402 aberrants, which is 1.2% as stated. Of these, 215, or more than half, have I, V, II insert, and 92 are cases in which the fusion of two genitals excluded an ocular causing the irregularity. This leaves only 92 or 0.28% as somewhat scattered aberrant variants.

Returning to the Dumpling Islands series, we find that those exceeding 30 mm. in diameter are considered as the developed series because the percentages are virtually the same for all specimens over this size, and differ from those for specimens under this size as such are still developing. This knowledge can only be attained by studying large series, where the possible irregularities of a small series are eliminated.

The series of 30 to 40 mm. in diameter (1,750 specimens) has 2.4% with ocular I insert; 95% have I, V; and 0.9% have I, V, IV insert. The aberrants are unusually frequent in this lot, 36 specimens or 2%. Of these variants, ten specimens have oculars I, IV insert; three have V, II; five V, IV; and eighteen I, V, II insert.

The series of 40 to 50 mm. in diameter are about the size of the larger specimens met with in most localities. Of this size (2,900 specimens) 2.8% have ocular I only insert, a relatively high number, but on the principle of chances some fluctuation must be expected. One specimen has V only insert, being one of two such found in the whole lot. In 95% oculars I, V, and in 1.2% oculars I, V, IV are insert. The aberrants are 2%. Of these, three specimens have oculars I, II insert; nine have I, IV, three have V, II, two have V, IV, and 27 have oculars I, V, II insert.

The series of 50 to 60 mm. in diameter may be considered large specimens. Of this size (1,272 specimens) 2.4% have ocular I only insert; 94% have I, V, and 1.3% have I, V, IV insert. The arrested and progressive variants are practically the same as in the 30 to 40 mm. series, and the progressive variants as in the 20 to 30 mm. series. The aberrant variants are 2%.

They are: two specimens with oculars I, II insert; two, I, IV; three, V, IV; two, V, II; sixteen, I, V, II (text-fig. 145); and one with I, IV, II insert and V, III exsert. In this last case genitals 4, 5 are fused (text-fig. 147), shutting out ocular V, so that it is evidently a case of incomplete I, V, IV, II. It is the only instance found of just this combination in any sea-urchin.

At Dumpling Islands this species attains an exceptionally large size, and the next two sizes could not be collected often at other localities with which I am acquainted. The series 60 to 70 mm. in diameter is a small one (121 specimens) compared with the preceding. One specimen, 0.8%, has ocular I only insert, 95% have I, V, and two specimens, 1.6%, have I, V, IV insert. The second specimen was found in the last few examined. This is mentioned as, if by chance it had not been found, the percentage of progressive variants would have been much less, smaller even than in specimens 20 to 30 mm. in diameter. The generally expressed view that more oculars are insert in large specimens is quite without foundation in any species as far as my observations go. The aberrant variants of this series are 2%. Two specimens have oculars I, II insert (text-fig. 141), and one has I, V, II insert. The last series, 70 to 75 mm. in diameter (seven specimens), has 100% with oculars I, V insert. In a larger series probably some variants would have been found, but as far as it goes, it emphasizes the fact borne out by other species that the largest specimens have the species character, and that variants, both arrested and progressive, are more frequent in smaller individuals.

This large series from Dumpling Islands demonstrates that very young specimens show the passage from all exsert to ocular I insert and then to the bivium insert in ontogeny; older but yet young specimens show that progressive variants may appear even to the full specific proportion before the full percentage of the specific character is established. Specimens half-grown (30 mm. or more) have about the same percentage and range of the arrested, typical, and progressive characters as in fully adult specimens. Large individuals have no greater number of oculars insert than smaller individuals, excluding youthful stages.

Through the kind help of friends and from personal collecting, series of *Strongylocentrotus dröbachiensis* have been obtained from a number of localities for study, to see what the specific range might be. In all localities the character is for oculars I, V to be insert, but the percentage of this character varies with locality, and also the relative proportion of arrested and progressive variants varies very widely. The localities represented are arranged in the table on the basis of these characters (p. 143).

The most primitive type of the species seen is from Gullmar Fjord on the Swedish coast of Skagerrak. From this locality Dr. Mortensen kindly sent me fifty specimens. On inquiry he informs me that this fjord receives a considerable volume of fresh water from a river, so that the water is at times distinctly brackish. The specimens are medium sized individuals. Thirty percent have ocular I insert and only 58% oculars I, V insert. There are no typical progressive variants, but a high percentage of aberrants, 12%. Of these, one specimen has oculars I, II,

one has I, IV, and four have I, V, II insert. Specimens from this locality make an approach in primitiveness of structure to that shown in the 5 to 10 mm. series from Dumpling Islands, as regards the percentage of I, and I, V insert; also in both there are no cases of I, V, IV insert, but a considerable number of I, V, II. The Gullmar specimens are peculiar as in all individuals the spines are of a light purplish color with only an indication of the usual green. At Dumpling Islands the specimens are typically bright green; but in eight or ten out of the series there collected the spines are light purplish, so close to the Gullmar typical color that a specimen placed with them could not again be selected by its difference.

The next step in advance is found in a series which I collected at Pulpit Harbor, North Haven, Maine. This locality is a deep, very narrow bay, well removed from the open ocean. It receives fresh water from a considerable lake at the head of the bay and also by leaching from the shores, so that the water is distinctly brackish. The water is shallow, and the Echini, which are extremely abundant, were collected at low tide near the bridge which crosses this narrow bay. All individuals below 30 mm. in diameter were eliminated, and those tabulated ranged from this size up to 58 mm. in diameter. In this series (1,700 specimens) 10% have ocular I only insert, one specimen has ocular V alone insert; 88% have oculars I, V, and 0.5% have I, V, IV insert. This is a large percent of arrested and small percent of progressive variants for the species. The aberrants are 1%. Of these, three specimens have oculars I, II insert; four have I, IV; one has V, IV; and six I, V, II insert. As a whole, the Pulpit Harbor series makes a fairly close approach to the character seen in the immature 15 to 20 mm. series from Dumpling Islands, the similarity being in the percentages of the several characters and the relatively high number of aberrants with oculars I, V, II insert (table, pp. 142, 143).

A number of *Strongylocentrotus dröbachiensis* dredged off St. Pierre, south of Newfoundland, at the mouth of the St. Lawrence River, were kindly given to me by Mr. Owen Bryant. Of this lot (194 specimens), all good sized individuals, 6% have ocular I only insert, 92% I, V, and 0.5% I, V, IV insert. The aberrants are 2%, one specimen having I, IV and two I, V, II insert. The specimens of this locality are closely equivalent to the 20 to 30 mm. series from Dumpling Islands, as regards the percentage of insertness of oculars. A number of the St. Pierre specimens (22) are of a light cream color, both tests and spines, giving them a very peculiar appearance. Specimens of a similar color occur also in material from Puget Sound, Washington, but I have not seen such from any other localities.

As regards structural characters, the series described from Dumpling Islands, North Haven, Maine, would fall in place at this point, as indicated in the table (p. 143). The Dumpling Islands and the Calderwood Island next considered are both situated in the Fox Island Thoroughfare, at the mouth of Penobscot Bay, into which empties the large river of the same name. At Calderwood Island, when visited at extremely low course of tides, the Echini are vastly abundant, so numerous that in one morning before breakfast, with the help of an assis-

tant, I collected the 7,600 specimens here described. At this locality individuals do not attain a very large size, and observations were on various sizes without measurements, though none was very young. Of arrested variants, 3.2 % have ocular I only and 0.07 % have V only insert; 94 % have I, V; 1.6 % have I, V, IV; and 0.03 % have I, V, IV, II insert, thus presenting a wide range of characters. Aberrant variants are of many characters as might reasonably be expected in a large series, yet are relatively not numerous, only 76 specimens, or 1 %. Of these, one specimen has ocular IV only insert (text-fig. 140), a very rare variant in Echini; six specimens have oculars I, II insert; seventeen I, IV; nine V, IV; and eight V, II insert. Thirty-two specimens have oculars I, V, II, and two have V, IV, II insert, the latter a very rare variant (text-fig. 148). One specimen has oculars I, V, IV, III insert, II exsert. This very rare variant was seen in only one other specimen of this species (text-fig. 149, p. 134). The character of the Echini as regards ocular plates from the Calderwood locality is practically the same as in the Dumpling Island specimens, but is slightly more progressive.

At York, Maine, a series was collected in tide pools. The conditions are rocky shores exposed to the open ocean. The specimens (2,700) varied in size from small to large, but none was very young. Only 0.9 % have ocular I alone insert, a smaller proportion than in any locality previously considered. Oculars I, V are insert in 97 %, the highest average of any locality studied. As this is the species character, specimens from this locality may in a sense be considered as the nearest approach to the ideal of the species. As progressive variants, 1.4 % have oculars I, V, IV insert and one specimen (text-fig. 139, p. 132) has oculars I, V, IV, II insert. The aberrants are relatively few, 0.9 %. They are two specimens with oculars I, IV insert; six with V, IV; six with V, II; and eleven with I, V, II insert. It is interesting to see that in these later series, as the relative frequency of oculars I, V, IV insert increases, concurrently the number of the aberrant variant I, V, II insert proportionately decreases.

Up to this point the series from the several localities have gradually decreased in the primitive character of ocular I only insert and gained in the species character, the bivium insert, finding its maximum of 97 % in the York locality. There has also been a slight gain gradually in the progressive character of oculars I, V, IV insert. From here on in the succeeding localities considered, with slight fluctuations, the bivium gradually decreases its dominance and the progressive variants concurrently increase, thus approaching other species of the genus which are further evolved in this character (compare pp. 143 and 162).

Mr. A. P. Romine very kindly sent me a fine series of this species from Friday Harbor, Puget Sound, Washington. The locality is at the entrance to the Sound, and the water is presumably typically salt. The specimens average large, those tabulated ranging from 40 to 85 mm. in diameter. A specimen of *S. dröbachiensis* from Alaska, in the United States Fish Commission Collection, measures 90 mm. in diameter, but otherwise the maximum Puget Sound specimens are the largest seen or recorded. Of this series, in 1,200 specimens, 96 %

have the typical character of oculars I, V insert. In 0.9%, ocular I only is insert, and in 2.6% oculars I, V, IV are insert; one specimen, 0.1%, has I, V, IV, II insert. It is interesting to see how regularly this rare progressive variant crops out in almost every large series. The aberrant variants are few, eight specimens, or 0.8%. Of these, two have V, IV, and six I, V, II insert. In the percentage of typical arrangement also of arrested, progressive, and aberrant variants, the Puget Sound specimens are extremely close to those from York, Maine, but are slightly more progressive. In this lot there are ten specimens, 1%, which are light cream color, similar to the color commonly seen in *Echinus acutus* or *affinis*. This peculiar color was also seen in specimens from St. Pierre, Newfoundland, as noted, but from no other locality. It is interesting to see how closely one can correlate not only the typical character but also the relative frequency of variations in specimens collected at such widely distant localities.

From Massachusetts Bay, mostly in tide pools at Nahant, a series of 588 specimens was examined. Of these, 1.4% have ocular I only insert; 95% have I, V; and 2.2% have oculars I, V, IV insert. One specimen (text-fig. 139a, p. 132) has oculars I, V, IV, II insert, the extreme progressive variant of the species. The aberrant variants, 1.5%, are one specimen with oculars I, IV insert; one with V, IV; and seven with I, V, II insert. This is an unusually large proportion of I, V, II for a locality where I, V, IV is at all common.

Through the kindness of Mr. Dwight Blaney of Boston, and from my own collecting, a series of specimens was obtained from Frenchman's Bay, Maine. They were all from shallow water, and varied from small to large, though none was very young. Of this series (4,000 specimens) one, 0.03%, has all oculars exsert, an extreme and very rare arrested variant (text-fig. 135, p. 132). It is the only one found in the species except as it occurs in a very early stage as a developing character. In 1.9% ocular I only is insert; in 94% oculars I, V; and in 3.3% oculars I, V, IV are insert. In two specimens, or 0.05% oculars I, V, IV, II are insert. This shows a distinct gain in progressive variants over those previously considered. In several of the following series there are no cases of I, V, IV, II insert, but this is so rare a character, that it cannot be expected in small series. In large series it appears, however, with marked regularity as shown in the table. The aberrant variants of Frenchman's Bay are 47 specimens, or 1%. They are in detail, one specimen with ocular II only insert, a very rare variant; eight have oculars I, IV insert; four have I, II; five V, II; and twenty-nine have I, V, II insert.

From Harpswell, Maine, through the kindness of Dr. F. D. Lambert, of Tufts College, I have 300 specimens. They are all large individuals. Of arrested variants, 2.7% have ocular I only insert, one has V only, 92% have I, V, and 3.7% I, V, IV insert. The aberrants are 1%. Of these, two specimens have oculars V, II insert and one I, V, II insert.

Through the kindness of Mr. J. Henry Blake, specimens were obtained from Truro, Massa-

chusetts. This is of interest as the most southern locality represented. The specimens were dredged in shallow water under open ocean conditions. In this series there are many small as well as large specimens, so for comparison they are divided into two sets. The first from the Truro locality, is composed of small specimens, 20 to 30 mm. in diameter. In this set (1,100 specimens) only 0.3 % have ocular I only insert. This is a smaller proportion than in the larger series, doubtless a mere coincidence, but it shows that the specimens are fully developed in regard to this character, whereas the 20 to 30 mm. series from Dumpling Islands (see table, p. 142) is less developed in this character than larger individuals of that locality. The Truro specimens of this series have 96 % with oculars I, V insert, a higher percent than the larger. On the other hand, of the progressive variant I, V, IV insert, there are only 2.9 % instead of 4.3 % as in the larger series, indicating that this character develops in later growth. Of aberrant variants there is 1 %, consisting of five specimens with oculars I, IV and eight with I, V, II insert. The second set from the Truro locality consists of larger specimens ranging from 30 to 60 mm. in diameter. In this series (1,700 specimens) 0.6 % have ocular I only insert, 94 % have I, V, and 4.3 % are progressive variants with I, V, IV insert. One specimen, 0.06 %, has I, V, IV, II insert. The aberrant variants are 1 %, of which there are six specimens with oculars I, IV insert; two with V, IV; two with V, II; and ten with I, V, II insert. This series has gained in I, V, IV insert at the expense of the I, V as compared with the smaller series. It is of interest as it is marked by the least number of arrested variants and the greatest number of progressive variants of any locality on the New England coast (table, p. 143).

A series of 200 specimens from Labrador is interesting as representing a northern locality. Arrested variants with ocular I only insert are rather frequent, 2.5 %. The specimens are so small that it is possible that some of them are developing individuals and a series of larger specimens might show fewer arrested variants. The same statement also applies to the next series considered. The Labrador lot has 87.5 % with ocular I, V insert, and 7.5 % of progressive variants with oculars I, V, IV insert. Aberrants are 2 %, being three specimens with oculars I, IV, and one with I, V, II insert.

Through the kindness of Dr. Mortensen I have a series of 35 specimens from Iceland and the Farøe Islands. These both show practically identical characters, so are treated together. They are of special interest as being the most northern locality represented and also as showing the most progressive character seen in the species. The specimens are medium sized, a few are small. Of arrested variants 11 % have ocular I only insert, a strikingly high percentage for the species and especially as the progressive variants are frequent. Only 60 % have oculars I, V insert, almost the lowest percentage known in the species, and 20 % have as progressive variants oculars I, V, IV insert. This is way ahead of that known from any other locality and is directly comparable to the progressive variants of *Strongylocentrotus purpuratus* from California, which in this respect is the most progressive species of the genus. The aberrant variants

are relatively numerous, three specimens, or 9 %. Of these, one has oculars I, IV and two have I, V, II insert. A large series from that region would be well worth studying.

The study of *Strongylocentrotus dröbachiensis* from different localities was made on this species as an available form, to gather what might be the range in differential development under various conditions and in different areas. The result shows that there is a very considerable difference with locality, and the same fact is borne out by observations on other species, as shown in *Cidaris affinis*, *Arbacia punctulata*, *Tripneustes esculentus*, and *Echinometra lucunter*. It opens up a line of inquiry which would be worth following further in these or other Echini.

To ascertain what is the cause of variation is difficult, so many factors enter into such a problem. The localities, however, represent certain groups of conditions, and percentages of arrested or progressive variants have a certain approximation to those groups, so that tentatively they may be ascribed to these conditions. The most primitive series occurred in deep reëtrant fjords, or bays, well removed from the open sea, which receive a considerable increment of fresh water. Such are Gullmar Fjord and Pulpit Harbor. The next more advanced group occurred near the mouths of large rivers, St. Pierre, Dumpling Islands, and Calderwood Island. Up to this point the arrested variants are in all localities more numerous than the progressive. The third group occurred in open sea water well removed from large rivers, the Truro locality being the purest open ocean conditions of the group; such are York, Puget Sound, Massachusetts Bay, Frenchman's Bay, South Harpswell, and Truro. In all of these the progressive variants are more numerous than the arrested variants. The last group is far northern, and as far as known, from pure open ocean conditions, Labrador, Iceland and Faröe Islands. Here the progressive variants are markedly in advance of arrested variants and also of the localities farther south.

In the series considered a curious relation is brought out in regard to which plates meet the periproct when three are insert. The normal progressive variant for the species, family, and order is for oculars I, V, IV to be insert, and the equivalent right-handed aberrant is I, V, II. If the I, V, IV is rare, then the I, V, II is relatively frequent, as in the Dumpling Islands series of 5 to 20 mm. in diameter; or in the adults of that locality, Gullmar Fjord, and Pulpit Harbor. On the other hand, if the I, V, IV is relatively more common, then the I, V, II insert becomes much less frequent, as seen in the series from Frenchman's Bay, Truro, and Labrador. This same relative preponderance is brought out also by other species. A striking case is *Sphaerechinus granularis*, in which (p. 126) I, V, IV is rare, 1 %, whereas I, V, II is common, 8 %. On the other hand, in *Toxopneustes atlanticus*, I, V, IV is common, 28 %, but I, V, II is rare, only 1 % (p. 122).

Returning to the consideration of other species of Echini, in *Strongylocentrotus eurythrogrammus*, a southern species from Australia, of 56 specimens, 93 % have oculars I, V insert. As an arrested variant, 2 % have ocular I only insert and, as progressive variants, 5 % have

oculars I, V, IV insert. It is interesting to see that in this far distant locality the same laws of ocular arrangement hold as on the New England coast.

In *Strongylocentrotus franciscanus* a very young specimen (text-fig. 150) has no genital

Table of Development of Ocular Plate Arrangement in Strongylocentrotus dröbachiensis, and Variation of the same in one Locality (text-figs. 131-149; pp. 129, 132, 134).

Number of specimens.			All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
133	Developing series, Maine and Massachusetts	51 specimens 2.5-4 mm. diam.	<i>29*</i> 15*	<i>71</i> 36						
		82 specimens 4-5 mm. diam.	<i>4</i> 3	<i>96</i> 79						
		800 specimens 5-10 mm. diam.	<i>0.1</i> 1	<i>46</i> 369		<i>52</i> 419				<i>1</i> 11
5,450	Developing series, Dumpling Islands, North Haven, Maine	2,000 specimens 10-15 mm. diam.		<i>19</i> 371		<i>80</i> 1,596	<i>0.3</i> 6			<i>1</i> 27
		1,400 specimens 15-20 mm. diam.		<i>7</i> 97		<i>92</i> 1,289	<i>0.4</i> 5			<i>1</i> 9
		1,250 specimens 20-30 mm. diam.		<i>5</i> 60		<i>93</i> 1,161	<i>1</i> 13	<i>0.1</i> 1		<i>1</i> 15
		1,750 specimens 30-40 mm. diam.		<i>2.4</i> 42		<i>95</i> 1,657	<i>0.9</i> 15			<i>2</i> 36
		2,900 specimens 40-50 mm. diam.		<i>2.8</i> 80	<i>0.03</i> 1	<i>95</i> 2,741	<i>1.2</i> 34			<i>2</i> 44
6,050	Developed series, Dumpling Islands, North Haven, Maine	1,272 specimens 50-60 mm. diam.		<i>2.4</i> 31	<i>0.08</i> 1	<i>94</i> 1,198	<i>1.3</i> 16			<i>2</i> 26
		121 specimens 60-70 mm. diam.		<i>0.8</i> 1		<i>95</i> 115	<i>1.6</i> 2			<i>2</i> 3
		7 specimens 70-75 mm. diam.				<i>100</i> 7				

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Ocular Plate Arrangement and Variation in *Strongylocentrotus dröbachiensis* from Different Localities (text-figs. 135-149, 176, pp. 132, 134, 153).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
50	Gullmar Fjord on the Swedish coast of Skagerrak	.....	$\frac{30}{15}$	.....	$\frac{58}{29}$	.....	.....	.....	$\frac{12}{6}$
1,700	Pulpit Harbor, North Haven, Me., 30-58 mm. diam.	.....	$\frac{10}{173}$	$\frac{0.06}{1}$	$\frac{88}{1,503}$	$\frac{0.5}{9}$	.....	.....	$\frac{1}{14}$
194	St. Pierre, Newfoundland	.....	$\frac{6}{12}$	.....	$\frac{92}{178}$	$\frac{0.5}{1}$	.....	.....	$\frac{2}{3}$
	Dumpling Islands, North Haven, Maine. (This series, given above, belongs here.) 6,050 developed specimens, 30-75 mm. diam.	.....	$\frac{2.5}{}$	$\frac{0.03}{}$	$\frac{95}{}$	$\frac{1.1}{}$	.....	.....	$\frac{2}{}$
7,600	Calderwood Island, Fox Island Thoroughfare, Maine	.....	$\frac{3.2}{242}$	$\frac{0.07}{5}$	$\frac{94}{7,157}$	$\frac{1.6}{118}$	$\frac{0.03}{2}$	.....	$\frac{1}{76}$
2,700	York, Maine (text-fig. 176, p. 153)	.....	$\frac{0.9}{25}$	$\frac{0.04}{1}$	$\frac{97}{2,610}$	$\frac{1.4}{38}$	$\frac{0.04}{1}$	.....	$\frac{1}{25}$
1,200	Friday Harbor, Puget Sound, Washington, 40-85 mm. diam.	.....	$\frac{0.9}{11}$	.....	$\frac{96}{1,149}$	$\frac{2.6}{31}$	$\frac{0.1}{1}$	.....	$\frac{1}{8}$
588	Massachusetts Bay, mostly from Nahant, Mass.	.....	$\frac{1.4}{8}$	.....	$\frac{95}{557}$	$\frac{2.2}{13}$	$\frac{0.2}{1}$	.....	$\frac{2}{9}$
4,000	Frenchman's Bay, Maine	$\frac{0.03^*}{1^*}$	$\frac{1.9}{75}$	.....	$\frac{94}{3,745}$	$\frac{3.3}{130}$	$\frac{0.05}{2}$	.....	$\frac{1}{47}$
300	South Harpswell, Maine	.....	$\frac{2.7}{8}$	$\frac{0.3}{1}$	$\frac{92}{277}$	$\frac{3.7}{11}$	.....	.....	$\frac{1}{3}$
2,800	Truro, Massachusetts, series 20-30 mm. diam. (1,100 specimens)	.....	$\frac{0.3}{3}$	.....	$\frac{96}{1,052}$	$\frac{2.9}{32}$	.....	.....	$\frac{1}{13}$
	Same locality, series 30-60 mm. diam. (1,700 specimens)	.....	$\frac{0.6}{11}$	.....	$\frac{94}{1,595}$	$\frac{4.3}{73}$	$\frac{0.06}{1}$	.....	$\frac{1}{20}$
200	Labrador	.....	$\frac{2.5}{5}$	$\frac{0.5}{1}$	$\frac{57.5}{175}$	$\frac{7.5}{15}$	.....	.....	$\frac{2}{4}$
35	Iceland and Faröe Islands	.....	$\frac{11}{4}$	.....	$\frac{60}{21}$	$\frac{20}{7}$	.....	.....	$\frac{9}{3}$
33,000		20	1,758	11	30,231	569	9	0	402

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

pores and ocular I only is insert; an older, but still very young specimen, 22 mm. in diameter, has the bivium insert, the species character. Of adults, 179 were examined, including a superb series of 61 specimens from Friday Harbor, Puget Sound, Washington, kindly sent me by Mr. A. P. Romine. Of this species, in 87 %, oculars I, V are insert (text-fig. 152). In 1 % ocular I alone is insert as an arrested variant. Both of the two specimens showing this character are adults, one being very large, 145 mm. in diameter (text-fig. 151). Of progressive variants

TEXT-FIGS. 150-153.—Ocular plate arrangement in *Strongylocentrotus franciscanus* A. Agassiz.

150. Monterey Bay, California. Young. Diam. 5.5 mm. R. T. J. Coll., 552. $\times 6.5$. Ocular I alone insert as a developing character, no genital pores.

151. Friday Harbor, Puget Sound, Washington. Diam. 145 mm. R. T. J. Coll., 906. $\times 1.6$. Ocular I alone insert, an arrested variant.

152. California. Diam. 154 mm. R. T. J. Coll., 724. $\times 1.6$. Oculars I, V insert, the typical character. An exceptionally large specimen (text-figs. 166, p. 149; 199, p. 171).

153. Vancouver, British Columbia. Diam. 126 mm. R. T. J. Coll., 725. $\times 1.6$. Oculars I, V, IV insert, a progressive variant.

11 % have oculars I, V, IV insert. The specimen from which text-fig. 152 was drawn is exceptionally large, 154 mm. in diameter, the largest seen, yet it has only the bivium insert; the progressive variants were all considerably smaller. One specimen only is aberrant with oculars V, II insert, ocular I being excluded from the periproct by the fusion of genitals 5, 1 as in text-fig. 146. Of the three adults here figured it is noteworthy that the largest specimen (text-fig. 152) has the smallest apical disc and the next smaller specimen, which is an arrested variant (text-fig. 151), has the largest apical disc (p. 87).

The most progressive species of the genus is *Strongylocentrotus purpuratus* from California. Through the kindness of Dr. W. K. Fisher, I received a fine series of specimens; with others, 120 have been studied. In this species 77 % have oculars I, V insert, 1 % is arrested with I only insert, and 22 % are progressive variants with I, V, IV insert. The species *eurythrogrammus*, *franciscanus*, and *purpuratus*, although they have oculars I, V insert as a typical

character, have a larger number of progressive variants as regards ocular plates than any other species of the genus (table, p. 162).

Strongylocentrotus gibbosus is a most unusual sea-urchin in that it has deeply bedded in the periproct a commensal crab, *Fabia chilensis* Dana. This crab is a very constant associate; but one specimen in 24 studied has no trace of a crab (text-fig. 155). The anomalous association of the crab very deeply modifies the relative position of the ocular plates. The crab in the cases seen occupies a position close to ocular IV and genital 3, as shown in the figures, and no variation was noted in this position. This species and *Gymnechinus* are the only Echini studied in which an aberrant arrangement of ocular plates is the dominant one. In 24 specimens one has I, V, IV insert (text-fig. 154), and four have all the oculars insert

TEXT-FIGS. 154-157.—Ocular plate arrangement in *Strongylocentrotus gibbosus* (Agassiz). Payta, Peru. The typical commensal crab, *Fabia chilensis*, in all but text-fig. 155. All figures $\times 4$.

154. Diam. 31 mm. R. T. J. Coll., 704. Oculars I, V, IV insert.

155. Diam. 28 mm. R. T. J. Coll., 702. Oculars V, IV insert. Crab wanting.

156. Diam. 42 mm. R. T. J. Coll., 703. Oculars V, IV, III insert, the typical character in this aberrant species; the periproct meets the interambulacra at the points marked X. The commensal crab is very clear and in its typical position (pp. 94, 128, 177).

157. Diam. 40 mm. R. T. J. Coll., 705. Ocular plates all insert.

(text-fig. 157). These are the only cases of all oculars insert seen in the genus. It is also interesting that in text-fig. 157 there is an interspace between ocular III and genital 3, where the periproct reaches the interambulacrum, and the same feature is shown in three areas in text-fig. 156. This is comparable as a parallelism to a similar condition of separation of ocular and genital plates in *Phormosoma* (p. 110). All the other specimens, 79 %, are aberrant in ocular arrangement. In five, oculars V, IV are insert; one of these has no associated crab (text-fig.

155), but yet retains the specific irregularity. Eight have V, IV, III insert (text-fig. 156), a very unusual arrangement, seen in only three other cases in the order Centrechinoida, yet it is the dominant character, 33 %, in *S. gibbosus*. This arrangement of oculars with V, IV, III insert was found as an aberrant variation in six cases in the Cidaroida, as described in *Cidaris affinis* and *Eucidaris tribuloides* (pp. 96, 97, 99). Six specimens, 25 %, have oculars I, V, IV, III insert, again a rare arrangement in the order, but frequent in the Cidaroida. In young specimens of *gibbosus* a few mm. in diameter all oculars are exsert. In the Strongylocentrotidae, of the species studied, two are characterized by having oculars all exsert; all others have typically the bivium insert except the aberrant *S. gibbosus* (pp. 162, 164).

The Echinometridae as here restricted includes Echinometra and allies, which are elliptical in outline through a sidewise axis, a character peculiar to this group of Echini only. In this family, as in the Arbaciidae, when ocular plates enter the periproct, it is in the sequence V, I, not I, V, as in the Echinidae and Strongylocentrotidae. On this basis, when only one ocular is insert, it should be V, and this is true as a dominant rule; occasionally, however, ocular I alone is insert. Such cases may be considered variants toward the character of the associated families in which, if only one plate is insert, that plate is typically ocular I. The rule is not quite so constant as in the Arbaciidae, in which, if one plate is insert, it is ocular V with very rare exceptions. The most primitive species of Echinometra on the basis of ocular plate arrangement is *E. oblonga*. Of this species (44 specimens) in 98 % all the oculars are exsert, and in 2 % ocular V is insert as a progressive variant. In *Echinometra viridis* (25 specimens), 96 % have all oculars exsert, and 4 % ocular V insert. *Echinometra mathaei* (159 specimens) has typically, 79 %, all oculars exsert; of progressive variants 19 % have V, and 1 % have V, I insert; 1 % is aberrant with oculars V, II insert.

Of *Echinometra lucunter* a large series was studied, and it shows different facies in two widely separated localities. In the West Indian area (578 specimens) typically, 57 %, ocular V alone is insert (text-fig. 159). As arrested variants 17 % have all oculars exsert (text-fig. 158), the typical character of *E. oblonga*. As progressive variants 25 % have oculars V, I insert (text-fig. 160), like the typical character of *E. van brunti*, and 0.3 % have V, I, IV insert (text-fig. 161). In *Echinometra lucunter* from Bermuda considerable difference exists. In 176 specimens from that locality ocular V is typically insert in 46 %. The arrested variants, however, are less frequent, only 9 % having all oculars exsert. Also the progressive variants are much more frequent than in the West Indian form, there being 43 % with V, I, and 0.6 % with V, I, IV insert. The Bermudan form, while having typically ocular V insert as in the West Indian, is therefore distinctly more progressive as shown by its variants, and makes a closer approach to the character seen in the next higher species, *E. van brunti*. The Bermudan form of *E. lucunter* is notable for its large size and robust character. One specimen in my collection from that locality measures 90 mm. through the long axis. While in *Echinometra*

lucunter 413 specimens have ocular V alone insert, only four have ocular I alone insert, showing the strong dominance of this character. In the whole number (754) examined, there are but two specimens, 0.3 %, with an aberrant arrangement of oculars. In one, oculars V, IV are insert, and in the other V, II alone reach the periproct (tables, pp. 163, 164).

TEXT-FIGS. 158-161.—Ocular plate arrangement in *Echinometra lucunter* (Linné). Hayti, West Indies. All figures $\times 4$. (Compare text-figs. 111-114, p. 115.)

158. Length 41 mm., through 3, I. R. T. J. Coll., 768. Oculars all exsert, an arrested variant.
 159. Length 55 mm., through 3, I. R. T. J. Coll., 769. Ocular V insert, the typical character.
 160. Length 52 mm., through 3, I. R. T. J. Coll., 770. Oculars V, I insert, a progressive variant.
 161. Length 41 mm., through 3, I. R. T. J. Coll., 771. Oculars V, I, IV insert, an extreme progressive variant.

Echinometra van brunti is an interesting form as it is apparently the highest species of the genus, judging from the ocular plates. In 76 specimens the typical character is to have oculars V, I insert, which occurs in 72 %. As arrested variants only 11 % have oculars all exsert, which is the character of *E. mathaei*; in 12 % V only is insert, which is the character of *E. lucunter*; and in 4 % ocular I only is insert. As a progressive variant, 1 % have V, I, IV insert. It would be most interesting to get a large series of this species for comparative study, but it is felt that the number seen is enough to give a fair basis for comparison.

In *Heterocentrotus mammillatus* (35 specimens) 80 % have oculars all exsert, 11 % are progressive variants with ocular V insert; in one specimen ocular I, and in one oculars V, I are insert. One specimen is aberrant with oculars V, II insert. In the nearly allied *Heterocentrotus trigonarius* (47 specimens) typically, 60 %, all oculars are exsert; in 28 % ocular V is insert, in 4 % ocular I and in 9 % oculars V, I are insert. In *Colobocentrotus atratus* (82 specimens) 99 % have all oculars exsert, and in 1 % ocular V is insert, as a progressive variant.

The Echinometridae as a family is characterized by very close adherence to the rules of ocular arrangement. In the whole 1,222 specimens examined, only four aberrants were found; of these, three have oculars V, II and one has V, IV insert (tables, pp. 163, 164).

Having considered the character of ocular plates in their relation to the genitals and to

the periproct as typical developing and adult features, and as variants in many species of fossil and living Echini, the characters may be summarized as follows. In the Ordovician *Bothriocidaris archaica* the oculars form a continuous ring with genitals on their dorsal border (text-fig. 162). In the Devonian to Carboniferous usually, as in *Melonechinus* (text-fig. 163), oculars and genitals all reach the periproct and the corona. In the Mesozoic usually, as in *Cidaris coronata* (text-fig. 164), the genitals alone reach the periproct and oculars are all exsert. In the Recent, oculars are all exsert in the young individual. In the adult typically all oculars may still be exsert, or one, or more to all plates may travel in so as to reach the periproct, and the incoming, barring relatively rare exceptions, is in a perfectly definite order. Different species or genera attain as a character definite points along this line of differential development, and selected cases of coming in are shown in text-figs. 165 to 169. All plates may be typically exsert, as in *Echinus esculentus* (text-fig. 116, p. 117). One plate may be typically insert, when it is either ocular I, as in *Echinus magellanicus* (text-fig. 165), or ocular V, as in *Echino-*

TEXT-FIGS. 162-175.—Ocular plate arrangement in typical Echini. Each figure represents the typical character of the several species represented.

162. *Bothriocidaris archaica* sp. nov. Ordovician, Russia. From Plate 1, fig. 2. $\times 7$. Oculars very large, meeting in a ring, genitals small, dorsal to the oculars (p. 87).

163. *Melonechinus multiporus* (Norwood and Owen). Lower Carboniferous, St. Louis, Missouri. From Plate 56, fig. 6. $\times 3$. Oculars and genitals all meet the periproct and corona. Compare text-fig. 169. Genitals have many pores.

164. *Cidaris coronata* Goldfuss. White Jura, Sontheim. Stuttgart Museum 9,782. Enlarged. All oculars exsert. Plates of periproct in place, very rare for fossils of the genus (pp. 96, 174).

165. *Echinus magellanicus* Philippi. Patagonia. Diam. 26 mm. R. T. J. Coll., 773. $\times 2.7$. Ocular I insert (p. 119).

166. *Strongylocentrotus franciscanus* A. Agassiz. California. Diam. 112 mm. R. T. J. Coll., 699. $\times 1.7$. Oculars I, V insert (p. 144).

167. *Arbacia nigra* (Molina). Chili. Diam. 92 mm. R. T. J. Coll., 796. $\times 2.6$. Oculars I, V, IV insert (p. 116).

168. *Acrosalenia pseudodecorata* Cotteau. Bathonien, France. (After Cotteau, 1875-'80, Plate 246, fig. 6.) Oculars I, V, IV, II insert. Suranal plate is dorsal to genital 3 (p. 112).

169. *Phyllacanthus baculosa* (Lamarek). Mauritius. Diam. 41 mm. R. T. J. Coll., 695. $\times 2.7$. All oculars insert. (Compare text-fig. 163, p. 102; Plate 3, figs. 3, 4.)

170. *Phormosoma placenta* Wyville Thomson. Off Cape Sable to Cape May, 956 fath. Diam. 56 mm. R. T. J. Coll., 707. $\times 3.5$. All oculars insert and interspaces exist between oculars and genitals so that the periproct reaches the interambulaera. Genitals are split ventrally. Ambulaeral plates are simple primaries in the placogenous zone. Interambulaeral plates originate against oculars as usual (pp. 63, 110, 177; Plate 3, fig. 8).

171. *Holactypus hemisphericus* Desor. Inferior Oolite, Leckhampton Hill, England. Diam. 28 mm. R. T. J. Coll., 738. $\times 9$. Oculars all excluded from the center by genitals (p. 170).

172. *Cassidulus subquadratus* Conrad. Upper Cretaceous, Holly Springs, Mississippi. After W. B. Clark, 1893, Plate 31, fig. 1h. Enlarged. Oculars I, V reach the center, other oculars are excluded from the center by the genitals.

173. *Toxobrissus pacificus* A. Agassiz. Adapted from A. Agassiz, 1904, text-fig. 279, p. 193. Enlarged. Oculars I, V are virtually insert, although actually ocular I is shut out by the posterior extension of genital 2.

174. *Micraster coranguineum* (Lamarek). Cretaceous, England. Length 55 mm. R. T. J. Coll., 521. $\times 6.7$. Oculars I, V, IV reach the center, others excluded from the center by the genitals. Compare text-fig. 167 (p. 92).

175. *Ananchytes ovatus* (Leske). Cretaceous, Sussex, England. Length 67 mm. Student Laboratory Coll., 172, Harvard University. $\times 2.4$. Oculars I, V, IV, II reach the center, III only being excluded from the center by the genitals. Compare text-figs. 126 and 168 (pp. 92, 167).

metra lucunter (text-fig. 159, p. 147). Two plates may be insert, when it is typically the bivium, as in *Strongylocentrotus franciscanus* (text-fig. 166). Three plates may be insert, when it is the bivium and left posterior plate of the trivium, as in *Arbacia nigra* (text-fig. 167). When four plates are insert, it is typically the bivium and posterior pair of the trivium, as in *Acrosalenia pseudodecorata* (text-fig. 168). I have shown this character in many cases as a variant but have not seen a species in which it is the character, so have copied the figure from Cotteau (1875-'80), as he says that four plates are typically insert in that species. All ocular plates may be insert, as in *Phyllacanthus baculosa* (text-fig. 169), when we have a character which is a close approach to that dominant in the Upper Palaeozoic (text-fig. 163). The next differential character to appear is for interspaces to develop between the ocular and genital plates, so that the periproct comes in contact with the interambulacra, as in *Phormosoma placenta* (text-fig. 170).

Turning to the irregular Echini, we find in part a parallel series to that seen in the regular Echini. As the periproct is eccentric, of course oculars cannot reach that structure, but if oculars reach the center line, they may be considered insert, or if excluded from the center line by junction of the genital plates, they may be regarded as exsert. Oculars may be all exsert, as in *Holotypus* (text-fig. 171; compare text-fig. 164). The bivium alone may be insert, as in *Cassidulus* (text-fig. 172; compare text-fig. 166). In some species, as *Toxobrissus* (text-fig. 173), the plates of the bivium may be separated by the posterior extension of the madreporite, but as this plate radially speaking is out of place, the oculars I, V may still be considered as morphologically insert. Or it could be looked at from another point of view and ocular V alone regarded as insert (as is common in the Arbaciidae), the other four oculars being shut out from the center by the contact of the genitals. Three ocular plates may be insert, when it is the bivium and left posterior plate of the trivium, as in *Micraster* (text-fig. 174; compare text-fig. 167). Or, finally, four ocular plates may be insert, when it is the bivium and posterior pair of the trivium, as in *Ananchytes* (text-fig. 175; compare text-fig. 168).

The typical character of arrangement of ocular plates and the range of variation are expressed diagrammatically by block lines in text-fig. 176. Each block represents the frequency of the character in the species, as given in the tables (pp. 100, 101, 143, 154-163). An exception to this statement is in the cases of *Strongylocentrotus lividus* (p. 126) and *Phyllacanthus annulifera* (p. 102) in which additional specimens, tabulated after this diagram was drawn, somewhat altered the facts and percentages, but it was not deemed of sufficient importance to omit the observations, and there was no opportunity to alter the diagram. The characters are all given correctly to scale excepting that when one exists in less than 1 % of the specimens, it is represented by a line the thickness of which has no relation to the frequency of the same. On the left of the diagram is given the character *a*, all oculars exsert. This is an invariable feature in the specimens of *Echinus affinis* observed (p. 118). It is also the character of the

adults of most Mesozoic and the young of all modern species of regular Echini. Passing to *Echinus esculentus*, all exsert is still strongly the character, but one plate may be insert as an infrequent progressive variant (p. 118). In *Arbacia punctulata*, a similar condition prevails, but one plate insert is a more frequent variant and rarely two or three plates are insert. *Strongylocentrotus lividus* has typically all oculars exsert, but one insert is a frequent and two insert a rarer progressive variant (p. 126).¹ *Echinometra mathaei* has a lower percentage of all exsert and a consequent gain of progressive variants (p. 146). In *Echinus angulosus* the progressive variants become more strongly marked, especially as compared with the northern species of the genus shown (p. 119).

In *Salenocidaris varispina*, instead of all exsert, one ocular insert is the species character, and the feature of oculars all exsert passes into the phase of an arrested variant (p. 112). *Echinus magellanicus* has typically one ocular insert; all oculars are exsert as an occasional arrested variant, or I, V insert as an occasional progressive variant. In no case seen were oculars I, V, IV insert, the space for which is indicated in the diagram at X, but in one specimen oculars I, V, IV, II are insert, as an extreme progressive variant (p. 119). *Echinometra lucunter* from the West Indian fauna (p. 146) has one ocular insert as the species character, but all exsert is a frequent arrested variant and two insert a more frequent progressive variant, with rarely three plates insert. In the same species from Bermuda (p. 146) a different condition prevails, as arrested variants are rarer and progressive variants are much commoner than in the southern form.

With *Strongylocentrotus fragilis* two oculars insert becomes the dominant character, with all exsert or one insert as frequent arrested variants (p. 128). In *Echinometra van brunti* two plates insert is strongly the dominant character with all oculars exsert or one insert as relatively infrequent arrested variants; and three oculars insert as a somewhat rare progressive variant (p. 147). *Strongylocentrotus dröbachiensis* from York, Maine, has very strongly two oculars insert, with but few arrested and progressive variants (p. 138). From here on, the species shown have less of the bivium insert, few arrested variants with all exsert or one insert, and progressively more with three or four plates insert. *Toxopneustes variegatus* shows a distinct gain of progressive variants over the last species considered, and a consequent dropping of the bivium insert character (p. 121). In *Strongylocentrotus purpuratus* there is a still further reduction of the I, V insert and gain of the I, V, IV insert. A striking case is the *Toxopneustes atlanticus* in which progressive variants are much in excess of what is found in the closely allied *T. variegatus* (p. 122).

With *Tripneustes esculentus* from the West Indian fauna (p. 124), three oculars insert becomes the dominant character. In this species from this area two oculars insert is a very

¹ In the diagram (text-fig. 176) the first 170 specimens only of *Strongylocentrotus lividus* are included. Recently, and too late to alter the diagram, this number was increased to 1,163 specimens. In this larger series the percentages (pp. 126, 162) are altered somewhat from that shown in the diagram and one specimen, 0.1% has oculars I, V, IV insert, a feature not given in this diagram.

common arrested variant in frequency closely approaching the dominant character, and four oculars insert is a common progressive variant; rarely all oculars are insert. *Arbacia nigra* has strongly three oculars insert with no progressive variants, but occasional arrested variants of all exsert, and frequent arrested variants with one or two oculars insert (p. 116). This species covers the same range of characters as shown in *Arbacia punctulata*, but in very different proportions. *Centrechinus setosus* has strongly three oculars insert as the species feature and is almost the only species in the order in which the variation covers six characters. All exsert or one or two oculars insert occur as rare arrested variants, and four oculars or all insert are frequent progressive variants (p. 108). Of *Centrostephanus rodgersi* there are few observations, but as far as they may be trusted, it is the strongest three oculars insert of any species known, with frequent progressive variants having four or all oculars insert (p. 110). *Eucidaris tribuloides* has strongly three oculars insert as a dominant character (p. 97). Its range of variation covers practically all the characters known in regular Echini from the Lower Carboniferous up. The only exceptions to this statement are cases of Echini that typically have an aberrant ocular arrangement, as *Gymnechinus pulchellus* (p. 120) and *Strongylocentrotus gibbosus* (p. 145). The arrested variants of *Eucidaris tribuloides* are few, with all oculars exsert, or one or two insert. Progressive variants are common with four or much oftener five oculars insert. In no sea-urchin studied is four oculars insert a typical species character, though this is said (Cotteau, 1875-'80) to be the case in *Acrosalenia pseudodecorata* Cotteau.

With *Phyllacanthus annulifera* all oculars insert is the character with three or four oculars insert as frequent arrested variants (p. 102). In *Phyllacanthus baculosa* all oculars are insert as a strong species feature (p. 102). The only possible variants on this line of development are arrested, and such occur with three or four plates insert as rare arrested variants. In *Aspidodiadema nicobaricum* all oculars are strongly insert and no variation is known (p. 104). Those cases given in the diagram are selected, but almost any of the species shown in the tables of ocular plate arrangement could be intercalated in the diagram and there find an harmonious place in the scheme of differential structure.

The accompanying tables show the characters of ocular plates in the species studied. The table for the Cidaroida is on pp. 100, 101 and for *Strongylocentrotus dröbachiensis* on pp. 142, 143. In tabulating characters the only specimens omitted were those that had no locality, where this was an important item; also 71 that had three, four, or six areas, and some eight specimens that were so distorted that they could not properly be included. The general relation of percentages is considered on p. 93. All aberrant variations in the Centrechinoidea are given in the last table (p. 164). As the relation of ocular plates to the genitals and periproct plays such a distinct and definite part in geological sequence, in ontogeny, in variation, and in geographical distribution, it seems that they may be accepted as a feature of importance in the study of Echini. It seems also that they make a reasonable basis where differences occur on which to arrange the systematic sequence of species within the genus.

- 605 *Echinus affinis*
200 *Echinus esculentus*
2,100 *Arbacia punctulata*,
 Wood's Hole
170 *Strongylocentrotus lividus*
159 *Echinometra mathaei*
100 *Echinus angulosus*
26 *Salenocidaris varispina*
161 *Echinus magellanicus*
578 *Echinometra lucunter*,
 West Indies and Florida
175 *Echinometra lucunter*,
 Bermuda
55 *Strongylocentrotus fragilis*
76 *Echinometra van brunti*
2,700 *Strongylocentrotus dröbach-*
 ensis, *York, Maine*
1,013 *Toxopneustes variegatus*
120 *Strongylocentrotus purpuratus*
1,463 *Toxopneustes atlanticus*,
 Bermuda (45-60 mm. diam.)
455 *Tripneustes esculentus*,
 West Indies and Florida
246 *Arbacia nigra*
1,168 *Centrochinus setosus*
12 *Centrostephanus rogersi*
849 *Eucidaris tribuloides*
12 *Phyllacanthus annulifera*
106 *Phyllacanthus baculosa*
47 *Aspidodiadema nicobaricum*

TEXT-FIG. 176.—Diagram showing percentages of typical ocular arrangement and variation in selected species, from the tables, pp. 100, 101, 143, 154-163. Lettering: *a*, all oculars exsert; *b*, oculars I or V insert; *c*, oculars I and V insert; *d*, oculars I, V, IV insert; *e*, oculars I, V, IV, II insert; *f*, all oculars insert.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida.

Number of specimens.	Order CENTRECHINOIDA. Suborder AULODONTA:	All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Hemicidaridae.								
15	<i>Hemicidaris cartieri</i> d'Orbigny. Jurassic, Europe.	$\frac{100}{15}$ *							
6	<i>Hemicidaris hoffmanni</i> Agassiz. Jurassic, Europe.	$\frac{100}{6}$							
169	<i>Hemicidaris intermedia</i> (Fleming). Jurassic, Europe. (Text-fig. 75.)	$\frac{89}{151}$	$\frac{8}{13}$		$\frac{3}{5}$				
58	<i>Hemicidaris crenularis</i> (Lamarek). Jurassic, Europe.	$\frac{81}{47}$	$\frac{16}{9}$		$\frac{2}{1}$				$\frac{2}{1}$
16	<i>Hemicidaris luciensis</i> d'Orbigny. Jurassic, Europe. (Text-figs. 76, 77.)	$\frac{13}{2}$	$\frac{31}{5}$		$\frac{56}{9}$				
18	<i>Hemicidaris langrunensis</i> Cotteau. Jurassic, Europe.	$\frac{11}{2}$	$\frac{22}{4}$		$\frac{67}{12}$				
10	<i>Hemidiadema stramonium</i> Agassiz. Jurassic, Europe.	$\frac{90}{9}$	$\frac{10}{1}$						
16	<i>Asterocidaris minor</i> Cotteau. Jurassic, Solles, France. (Text-fig. 78.)	$\frac{100}{16}$							
43	<i>Goniopygus peltatus</i> Agassiz. Jurassic, Europe.	$\frac{100}{43}$							
75	<i>Glypticus hieroglyphicus</i> Agassiz. Jurassic, Europe. (Text-fig. 79.)	$\frac{100}{75}$							
426		366	32	0	27	0	0	0	1
	Aspidodiademataidae.								
44	<i>Aspidodiadema meijerei</i> Döderlein. Hawaiian Islands, 241-294 fathoms.							$\frac{100}{44}$	
47	<i>Aspidodiadema nicobaricum</i> Döderlein. Hawaiian Islands, 165-500 fathoms. (Text-fig. 176.)							$\frac{100}{47}$	
10	<i>Dermatodiadema antillarum</i> A. Agassiz. West Indies, 687-955 fathoms. (Text-fig. 80.)							$\frac{100}{10}$	
22	<i>Dermatodiadema horridum</i> A. Agassiz. Galapagos Islands, 812 fathoms.							$\frac{100}{22}$	
123		0	0	0	0	0	0	123	0

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Suborder AULODONTA (continued).								
	Centrechinidae.								
18	<i>Pseudodiadema pseudodiadema</i> (Lamarek). Jurassic, Trouville; Yonne. (Text-figs. 81, 82.)	89* 16*	11 2						
1	<i>Magnosia punctata</i> Quenstedt. Jurassic, Nattheim. (Text-fig. 83.)	100 1							
3	<i>Cottaldia granulosa</i> (Münster). Cretaceous, Chamboy.	100 3							
4	<i>Phymechinus mirabilis</i> (Agassiz). Jurassic, Europe. (Text-fig. 84.)	75 3			25 1				
7	<i>Pedina rotata</i> Wright. Oolite, England.	100 7							
4	<i>Stomechinus granularis</i> Agassiz. Jurassic, Europe.	100 4							
28	<i>Stomechinus perlatus</i> Desmoulins. Jurassic, Europe.	100 28							
50	<i>Stomechinus bigranularis</i> (Lamarek). Jurassic, Europe. (Text-figs. 85, 86.)	88 44	2 1	2 1	8 4				
14	<i>Polycephus normannus</i> Desor. Oolite, Europe.	93 13	7 1						
37	<i>Orthopsis miliaris</i> (d'Archiac). Cretaceous, Algiers; Europe. (Text-fig. 87.)	100 37							
1,278	<i>Centrechinus setosus</i> (Leske). Atlantic and Pacific Oceans, several localities. De- veloping series, 8-40 mm. diam. (110 specimens). (Text-figs. 88-92.)	23 25	5 5	.....	9 10	55 60	5 5	3 3	2 2
	The same. Atlantic and Pacific Oceans, many localities. Devel- oped series, 40-108 mm. diam. (1,168 specimens). (Text-figs. 93-95, 176.)	0.2 2	0.2 2	0.1 1	1 11	57 671	17 194	22 254	3 33
	<i>Echinothrix calamaris</i> (Leske). Mauritius; Zanzibar; and loc. (?)					9 1		91 10	
	<i>Echinothrix diadema</i> (Linné). Mauritius; Hawaii; Bonin; Samoa.							100 18	

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Suborder <i>AULODONTA</i> (continued).								
	Centrechinidae (continued).								
2	<i>Centrostephanus asteriscus</i> A. Agassiz and Clark. Hawaiian Islands.	$\frac{100}{2}$ *							
12	<i>Centrostephanus rodgersi</i> A. Agassiz. Parramatta, N. S. W.; Port Jackson. (Text-figs. 96, 176.)					$\frac{67}{8}$	$\frac{25}{3}$	$\frac{8}{1}$	
4	<i>Centrostephanus longispinus</i> (Philippi). Mediterranean. (Text-fig. 97.)							$\frac{100}{4}$	
9	<i>Astropyga pulvinata</i> (Lamarck). Gulf of California. (Text-fig. 99.)							$\frac{100}{9}$	
12	<i>Astropyga radiata</i> (Leske). Hawaiian Islands.							$\frac{100}{12}$	
36	<i>Chaetodiadema pallidum</i> A. Agassiz and Clark. Hawaiian Islands. (Text-fig. 98.)							$\frac{100}{36}$	
1,548		185	11	2	26	740	202	347	35
	Echinothuriidae.								
4	<i>Asthenosoma hystrix</i> (Wyville Thomson). Off Cape Hatteras to Charleston, S. C., 258 fathoms.							$\frac{100}{4}$	
1	<i>Asthenosoma iijimai</i> Mortensen. Off Tokio, Japan, 55 fathoms. (Text-fig. 101.)							$\frac{100}{1}$	
3	<i>Asthenosoma owstoni</i> Mortensen. Sagami Sea, Japan.							$\frac{100}{3}$	
11	<i>Phormosoma placenta</i> Wyville Thomson. Off Cape Sable to Cape May, 956 fathoms. (Text-fig. 170.)							$\frac{100}{11}$	
19		0	0	0	0	0	0	19	0
	Suborder <i>STIRODONTA</i> .								
	Saleniidae.								
57	<i>Peltastes stellulata</i> Agassiz. Cretaceous, Europe.	$\frac{100}{57}$							

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Suborder <i>STIRODONTA</i> (continued).								
	Saleniidae (continued).								
70	<i>Pellastes wrighti</i> Desor. Cretaceous, Farrington, England. (Plate 4, fig. 7.)	100* 70*							
16	<i>Salenia scutigera</i> Agassiz. Cretaceous, Europe.	100 16							
20	<i>Salenia petalifera</i> Agassiz. Cretaceous, Europe and Algiers.	95 19	5 1						
16	<i>Salenia pattersoni</i> A. Agassiz. Off Cuba, 300 fathoms; Barbados, etc. (Plate 4, figs. 1, 2.)	31 5	69 11						
2	<i>Salenia cincta</i> A. Agassiz and Clark. Near Goto Island, Japan, 95 fathoms.		100 2						
10	<i>Salenocidaris profunda</i> (Duncan). North of Tristan da Cunha, 1,425 fathoms. (Text-fig. 102.)	30 3	70 7						
26	<i>Salenocidaris varispina</i> A. Agassiz. West Indies, 270-687 fathoms. (Text-fig. 176; Plate 4, fig. 6.)	27 7	73 19						
16	<i>Salenocidaris miliaris</i> A. Agassiz. Galapagos Islands; Japan.	19 3	81 13						
10	<i>Acrosalenia aspera</i> Agassiz. Jurassic, Europe.	100 10							
5	<i>Acrosalenia decorata</i> (Haime). Oolite, England.	60 3			40 2				
101	<i>Acrosalenia spinosa</i> Agassiz. Jurassic, Europe. (Text-fig. 103.)	1 1	7 7		92 93				
58	<i>Acrosalenia hemiciaroides</i> Wright. Jurassic, Europe. (Text-fig. 104.)	2 1	5 3		86 50				7 4
16	<i>Acrosalenia pustulata</i> Forbes. Jurassic, England.		6 1		63 10	19 3	6 1		6 1
12	<i>Acrosalenia willtoni</i> Wright. Jurassic, near Cirencester and Wilts, England. (Text-fig. 105.)		8 1		58 7	8 1	17 2	8 1	
435		195	65	0	162	4	3	1	5

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.	Suborder <i>STIRODONTA</i> (continued).	All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
10	Phymosomatidae. <i>Phymosoma delamarei</i> (Desor). Cretaceous, Algiers. (Text-fig. 106.)	.....	.....	.....	.....	.....	.....	$\frac{100^*}{10^*}$	.....
10		0	0	0	0	0	0	10	0
64	Stomopneustidae. <i>Stomopneustes variolaris</i> (Lamarck). Ceylon; Mauritius; Zanzibar. (Text-figs. 107-110.)	.....	$\frac{2}{1}$	.....	$\frac{70}{45}$	$\frac{22}{14}$	.....	.....	$\frac{6}{4}$
64		0	1	0	45	14	0	0	4
78	Arbaciidae. <i>Arbacia stellata</i> Gray. Gulf of California; Panama.	$\frac{95}{74}$	.....	$\frac{4}{3}$	.....	$\frac{1}{1}$	.....	.....	.....
141	<i>Arbacia lixula</i> (Linné). Mediterranean; Azores; Teneriffe.	$\frac{94}{132}$	.....	$\frac{6}{8}$	.....	.....	.....	.....	$\frac{1}{1}$
2,329	{ <i>Arbacia punctulata</i> (Lamarck). Woods Hole, Massachusetts (2,100 specimens). (Text-figs. 111-114, 200-205, 176.) The same. Florida (229 specimens).	$\frac{87}{1,832}$	$\frac{0.1}{2}$	$\frac{11}{238}$	$\frac{0.3}{7}$	$\frac{0.4}{9}$	.....	.....	$\frac{0.6}{12}$
67	<i>Arbacia dufresni</i> Blainville. Chili; Patagonia; Hawaiian Islands (?)	$\frac{76}{58}$	.....	$\frac{19}{3}$	$\frac{2}{1}$	$\frac{1}{2}$	.....	.....	$\frac{3}{5}$
76	<i>Arbacia spatuligera</i> (Agassiz). Peru.	$\frac{9}{7}$	.....	$\frac{30}{23}$	$\frac{14}{11}$	$\frac{33}{25}$	.....	.....	$\frac{13}{10}$
246	<i>Arbacia nigra</i> (Molina). Chili. (Text-figs. 167, 176.)	$\frac{1}{3}$	.....	$\frac{22}{55}$	$\frac{12}{30}$	$\frac{57}{139}$	.....	.....	$\frac{8}{19}$
2	<i>Coelopleurus floridanus</i> A. Agassiz. Cape Hatteras to Charleston, 63 fathoms.	$\frac{100}{2}$	.....	.....	.....	.....	.....	.....	.....
2,939		2,282	2	373	53	176	0	0	53

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the *Centrechinoidea* (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant
	Suborder CAMARODONTA.								
	Temnopleuridae.								
7	<i>Glyphocyphus radiatus</i> Desor. Cretaceous, Europe.							100• 7•	
11	<i>Trigonocidaris albida</i> A. Agassiz. West Indies.	100 11							
7	<i>Temnopleurus hardwickii</i> (Gray). Japan; Ceylon.	100 7							
34	<i>Temnopleurus toreumaticus</i> (Leske). China Seas; Japan; India.	100 34							
19	<i>Temnopleurus reevesii</i> Gray. Japan; Siam.	53 10	47 9						
22	<i>Salmacis alexandri</i> Bell. Australia.	100 22							
14	<i>Salmacis bicolor</i> Agassiz. Japan; Mauritius; Red Sea.	100 14							
12	<i>Salmacis sphaeroides</i> (Linné). Australia; Philippines; and loc. (?)	100 12							
34	<i>Mespilia globula</i> (Linné). Samoa; Japan; and loc. (?)	97 33	3 1						
139	<i>Microcyphus maculatus</i> Agassiz. Mauritius; Japan, etc.	93 136			1 1				1 2
8	<i>Amblypneustes formosus</i> Valentin. Australia; Tasmania.	100 8							
12	<i>Amblypneustes griseus</i> (Blainville). Australia.	100 12							
10	<i>Amblypneustes pallidus</i> (Lamarek). Australia.	100 10							
38	<i>Amblypneustes ovum</i> (Lamarek). Australia.	97 37	3 1						
33	<i>Holopneustes purpureus</i> A. Agassiz. Australia.	97 32		3 1					
400		378	11	1	1	0	0	7	2

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Suborder CAMARODONTA (continued).								
	Echinidae.								
605	<i>Echinus affinis</i> Mortensen. Off east coast of United States. 1,022-1,106 fathoms. (Text-figs. 115, 176.)	$\frac{100}{605}^*$							
8	<i>Echinus elegans</i> Düben and Koren. Off Cape Romain and loc. (?)	$\frac{100}{8}$							
10	<i>Echinus gracilis</i> A. Agassiz. Off Carolina and Martha's Vineyard.	$\frac{100}{10}$							
200	<i>Echinus esculentus</i> Linné. Plymouth, England; Isle of Man; Mediterranean. (Text-figs. 116, 117, 176.)	$\frac{97}{195}$	$\frac{3}{5}$						
129	<i>Echinus miliaris</i> Müller. Norway; England; Isle of Man.	$\frac{98}{126}$		$\frac{1}{1}$	$\frac{2}{2}$				
299	<i>Echinus microtuberculatus</i> Blainville. Mediterranean.	$\frac{96}{287}$	$\frac{2}{5}$	$\frac{1}{4}$	$\frac{0.3}{1}$				$\frac{1}{2}$
10	<i>Echinus melo</i> Lamarek. Mediterranean; England.	$\frac{90}{9}$	$\frac{10}{1}$						
127	<i>Echinus acutus</i> Lamarek. Plymouth, England; Norway; Bergen; Mediterranean.	$\frac{82}{104}$	$\frac{18}{23}$						
100	<i>Echinus angulosus</i> Leske. Algoa Bay; Cape Colony; South Africa. (Text-fig. 176.)	$\frac{54}{54}$	$\frac{30}{30}$	$\frac{4}{4}$	$\frac{9}{9}$	$\frac{2}{2}$			$\frac{1}{1}$
200	<i>Echinus magellanicus</i> Philippi. Patagonia; Straits of Magellan. Developing series, 2.5-5 mm. diam. (36 specimens). (Plate 3, fig. 14.)	$\frac{97}{35}$	$\frac{3}{1}$						
	The same. Falkland Islands; Straits of Magellan. Developed series (164 specimens). (Text-figs. 165, 176.)	$\frac{5}{9}$	$\frac{88}{145}$		$\frac{4}{7}$		$\frac{0.6}{1}$		$\frac{1}{2}$
16	<i>Echinus margaritaceus</i> Lamarek. Patagonia; Kerguelen Islands; Antarctic.	$\frac{6}{1}$	$\frac{6}{1}$	$\frac{6}{1}$	$\frac{56}{9}$	$\frac{6}{1}$	$\frac{6}{1}$	$\frac{6}{1}$	$\frac{6}{1}$
9	<i>Gymnechinus robillardii</i> (Loriol). Mauritius. (Text-fig. 179.)		$\frac{11}{1}$						$\frac{89}{8}$
14	<i>Gymnechinus pulchellus</i> Mortensen. Singapore; Gulf of Siam. (Text-figs. 177, 178.)								$\frac{100}{14}$

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Suborder CAMARODONTA (continued).								
	Echinidae (continued).								
5	<i>Toxopneustes maculatus</i> (Lamarek). Fiji Islands; Mauritius.		$\frac{20}{1}$ *		$\frac{80}{4}$				
38	<i>Toxopneustes pileolus</i> (Lamarek). Acapulco; Panama; Mauritius.		$\frac{8}{3}$		$\frac{92}{35}$				
25	<i>Toxopneustes semituberculatus</i> Valentin. Galapagos Islands.		$\frac{4}{1}$		$\frac{96}{24}$				
1,043	<i>Toxopneustes variegatus</i> (Lamarek). West Indies and Florida. (Text-figs. 176, 184.)		$\frac{1}{11}$	$\frac{0.1}{1}$	$\frac{90}{937}$	$\frac{8}{84}$	$\frac{0.2}{2}$		$\frac{0.8}{8}$
	<i>Toxopneustes atlanticus</i> (A. Agassiz). Bermuda. Developing series, 35-45 mm. diam. (587 specimens).		$\frac{0.9}{5}$	$\frac{0.2}{1}$	$\frac{81}{475}$	$\frac{16}{92}$	$\frac{0.3}{2}$		$\frac{2}{12}$
2,643	The same. Developed series, 45-60 mm. diam. (1,463 speci- mens). (Text-figs. 118-122, 176.)		$\frac{0.1}{1}$	$\frac{0.5}{8}$	$\frac{0.1}{2}$	$\frac{67}{983}$	$\frac{28}{415}$	$\frac{1.2}{18}$	$\frac{2.5}{36}$
	The same. Developed series, 60-77 mm. diam. (593 specimens).		$\frac{0.7}{4}$	$\frac{0.3}{2}$	$\frac{68}{401}$	$\frac{29}{171}$	$\frac{0.7}{4}$		$\frac{1.8}{11}$
16	<i>Tripneustes depressus</i> A. Agassiz. La Paz, California; and loc. (?)		$\frac{6}{1}$		$\frac{75}{12}$	$\frac{19}{3}$			
72	<i>Tripneustes variegatus</i> (Leske). Mauritius; Jeddah, Red Sea; Durban; Natal; Samoa; Indo-Pacific; Lord Howe Island; Hawaiian Islands.		$\frac{7}{5}$	$\frac{1}{1}$	$\frac{68}{49}$	$\frac{8}{6}$	$\frac{11}{8}$		$\frac{4}{3}$
	<i>Tripneustes esculentus</i> (Leske). Bermuda. Developed series, 50-145 mm. diam. (193 specimens). (Text-figs. 123, 196.)		$\frac{2}{3}$		$\frac{61}{117}$	$\frac{35}{67}$	$\frac{2}{3}$	$\frac{0.5}{1}$	$\frac{1}{2}$
703	The same. West Indies and Florida. Developing series, 19-50 mm. diam. (55 specimens).		$\frac{9}{5}$		$\frac{76}{42}$	$\frac{13}{7}$			$\frac{2}{1}$
	The same. West Indies and Florida. Developed series, 50-127 mm. diam. (455 specimens). (Text-figs. 124-127, 176.)			$\frac{0.4}{2}$	$\frac{36}{165}$	$\frac{33}{172}$	$\frac{18}{84}$	$\frac{1}{5}$	$\frac{6}{27}$
20	<i>Evechinus chloroticus</i> (Valentin). New Zealand.				$\frac{90}{18}$	$\frac{5}{1}$			$\frac{5}{1}$
6,292		1,444	259	19	3,290	1,021	123	7	129

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.	Suborder CAMARODONTA (continued).	All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Strongylocentrotidae.								
10	<i>Pseudoboletia indiana</i> (Michelin). Mauritius; Isle de la Réunion.				100* 10*				
48	<i>Sphaerechinus pulcherrimus</i> A. Agassiz. Japan.		$\frac{2}{1}$		$\frac{98}{47}$				
291	<i>Sphaerechinus granularis</i> (Lamarek). Mediterranean; Azores.		$\frac{1}{2}$		$\frac{89}{258}$	$\frac{1}{3}$	$\frac{1}{3}$		$\frac{9}{25}$
1,163	<i>Strongylocentrotus lividus</i> (Lamarek). Mediterranean; Fayal; England. (Text-figs. 128-130, 176.)	$\frac{75}{876}$	$\frac{17}{195}$	$\frac{2}{26}$	$\frac{4}{50}$	$\frac{0.1}{1}$			$\frac{1}{15}$
60	<i>Strongylocentrotus albus</i> (Molina). Patagonia.	$\frac{53}{32}$	$\frac{2}{1}$	$\frac{5}{3}$	$\frac{25}{15}$	$\frac{2}{1}$			$\frac{13}{8}$
55	<i>Strongylocentrotus fragilis</i> sp. nov. Catalina Islands, California; off California and Oregon coasts. (Text-fig. 176.)	$\frac{13}{7}$	$\frac{29}{16}$	$\frac{2}{1}$	$\frac{56}{31}$				
6	<i>Strongylocentrotus mexicanus</i> A. Agassiz. Cape St. Lucas.			$\frac{17}{1}$	$\frac{83}{5}$				
39	<i>Strongylocentrotus tuberculatus</i> (Lamarek). Japan; Sidney, Australia.		$\frac{3}{1}$		$\frac{92}{36}$	$\frac{3}{1}$			$\frac{3}{1}$
12	<i>Strongylocentrotus depressus</i> A. Agassiz. Japan and loc. (?)				$\frac{100}{12}$				
	<i>Strongylocentrotus dröbachiensis</i> (O. F. Müller). See tabulation of 27, 417 specimens exclusive of developing series, p. 143. The percentages only are given here. (Text-figs. 135-149.)	$\frac{0.004}{1}$	$\frac{2.7}{16}$	$\frac{0.04}{1}$	$\frac{94}{31}$	$\frac{2}{1}$	$\frac{0.03}{1}$		$\frac{1.2}{19}$
56	<i>Strongylocentrotus eurythrogrammus</i> (Valentin). Australia.		$\frac{2}{1}$		$\frac{93}{52}$	$\frac{5}{3}$			
179	<i>Strongylocentrotus franciscanus</i> A. Agassiz. California; Washington. (Text-figs. 151-153, 166.)		$\frac{1}{2}$		$\frac{87}{156}$	$\frac{11}{20}$			$\frac{1}{1}$
120	<i>Strongylocentrotus purpuratus</i> (Stimpson). California; Puget Sound. (Text-fig. 176.)		$\frac{1}{1}$		$\frac{77}{93}$	$\frac{22}{26}$			
24	<i>Strongylocentrotus gibbosus</i> (Valentin). Payta, Peru. (Text-figs. 154-157.)					$\frac{4}{1}$		$\frac{17}{4}$	$\frac{79}{19}$
2,063		915	220	31	765	56	3	4	69

* Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Typical Ocular Plate Arrangement and Variation in the Centrechinoida (continued).

Number of specimens.		All oculars exsert.	Oculars I insert; V, IV, II, III exsert.	Oculars V insert; I, IV, II, III exsert.	Oculars I, V insert; IV, II, III exsert.	Oculars I, V, IV insert; II, III exsert.	Oculars I, V, IV, II insert; III exsert.	All oculars insert.	Arrangement of oculars aberrant.
	Suborder CAMARODONTA (continued).								
	Echinometridae.								
44	<i>Echinometra oblonga</i> Blainville.	98*	2	2					
	Samoa; Hawaiian Islands; South Africa.	43*	1	1					
25	<i>Echinometra viridis</i> A. Agassiz.	96	4	4					
	West Indies:	24	1	1					
159	<i>Echinometra mathaei</i> Blainville.	79	19	1					1
	Red Sea; Durban; Natal; Mauritius; Bonin; Hawaiian Islands. (Text-fig. 176.)	126	31	1					1
754	<i>Echinometra lucunter</i> (Linné).	17	0.3	57	25	0.3			0.2
	West Indies and Florida (578 specimens). (Text-figs. 158-161, 176.)	97	2	332	144	2			1
	<i>The same.</i>	9	1	46	43	0.6			0.6
	Bermuda (176 specimens). (Text-fig. 176.)	15	2	81	76	1			1
76	<i>Echinometra van brunti</i> A. Agassiz.	11	4	12	72	1			
	Lower California; La Union; South America. (Text-fig. 176.)	8	3	9	55	1			
35	<i>Heterocentrotus mammillatus</i> (Leske).	80	3	11	3				3
	Mauritius; Indian Ocean; Bonin Island; and loc. (?)	28	1	4	1				1
47	<i>Heterocentrotus trigonarius</i> (Lamarck).	60	4	23	9				
	Hawaiian Islands; Mauritius; Tahiti; Palmyra Island.	28	2	13	4				
82	<i>Colobocentrotus atratus</i> (Linné).	99	1	1					
	Hawaiian Islands; Mauritius; Zanzibar; and loc. (?)	81	1	1					
1,222		450	10	473	281	4	0	0	4

*Italic numerals represent percentages, Arabic numerals the number of specimens observed.

Table of Aberrant Ocular Plate Arrangement in 48,541 Specimens of the Centrechinoida.¹

Total number of specimens.		Percentage of aberrants.												
		Oculars IV insert; I, V, II, III exsert.	Oculars III insert; I, V, IV, II exsert.	Oculars II insert; I, V, IV, III exsert.	Oculars I, IV insert; V, II, III exsert.	Oculars I, III insert; V, IV, II exsert.	Oculars I, II insert; V, IV, III exsert.	Oculars V, IV insert; I, II, III exsert.	Oculars V, III insert; I, IV, II exsert.	Oculars V, II insert; I, IV, III exsert.	Oculars I, V, III insert; IV, II exsert.	Oculars I, V, II insert; IV, III exsert.	Oculars I, IV, II insert; V, III exsert.	Oculars V, IV, III insert; I, II exsert.
58	<i>Hemicidaris crenularis</i> (Lamarck).	2	1											
1,278	<i>Centrechinus setosus</i> (Leske).	3			1			1					1	32
58	<i>Acrosalenia hemicydaroides</i> Wright.	7							1	1	2			
16	<i>Acrosalenia pustulata</i> Forbes.	6								1				
64	<i>Stomopneustes variolaris</i> (Lamarck).	6	1								3			
141	<i>Arbacia lixula</i> (Linné).	1	1											
2,329	<i>Arbacia punctulata</i> (Lamarck).	0.6	2		1	1		14						
67	<i>Arbacia dufresni</i> Blainville.	7	2					3						
76	<i>Arbacia spatuligera</i> Agassiz.	13						10						
246	<i>Arbacia nigra</i> (Molina).	8			1			13			1			4
139	<i>Microcyphus maculatus</i> Agassiz.	1	1	1										
299	<i>Echinus microtuberculatus</i> Blainville.	1			2									
100	<i>Echinus angulosus</i> Leske.	1			1									
200	<i>Echinus magellanicus</i> Philippi.	1					1			1				
16	<i>Echinus margaritaceus</i> Lamarck.	6										1		
9	<i>Gymnechinus robillardii</i> (Loriol).	89					8							
14	<i>Gymnechinus pulchellus</i> Mortensen.	100					14							
1,043	<i>Toxopneustes variegatus</i> (Lamarck).	0.8			2				1		5			
2,643	<i>Toxopneustes atlanticus</i> (A. Agassiz).	2			1				18	1	25		13	1
72	<i>Tripneustes variegatus</i> (Leske).	4					2		1					
703	<i>Tripneustes esculentus</i> (Leske).	4			1						26		2	1
20	<i>Evechinus chloroticus</i> (Valentin).	5			1									
291	<i>Sphaerechinus granularis</i> (Lamarck).	9						2			23			
1,163	<i>Strongylocentrotus lividus</i> (Lamarck).	1	1	5	4		2		3					
60	<i>Strongylocentrotus albus</i> (Molina).	13	1						4				2	1
39	<i>Strongylocentrotus tuberculatus</i> (Lamarck).	3			1									
33,000	<i>Strongylocentrotus dröbachiensis</i> (O. F. Müller).	1.2	3	2	81		29	33	34		215	1	2	2
179	<i>Strongylocentrotus franciscanus</i> A. Agassiz.	1							1					
24	<i>Strongylocentrotus gibbosus</i> (Valentin).	79						5					8	6
159	<i>Echinometra mathaei</i> Blainville.	1							1					
754	<i>Echinometra lucunter</i> (Linné).	0.3						1		1				
35	<i>Heterocentrotus mammillatus</i> (Leske).	3							1					
Total number of aberrants 704 =		10	3	8	97	1	56	82	4	63	4	300	1	11
													17	47

¹This table includes all aberrant variants of the Centrechinoida listed in the tables, pp. 142, 143, 154 to 163. See text-figs. 110, p. 114; 140-149, p. 134; 155, 156, p. 145; 177-179, p. 165; 182, p. 165; 196, p. 169.

SPECIAL CHARACTERS OF GENITAL PLATES.

Certain characters of genital plates are here taken up aside from their relations to the oculars, that have just been considered. The characters in genitals are subject to a great deal of variation. While the bearing of these variations is often obscure, for the most part they follow very definite lines. In my studies of post-Palaeozoic fossil and Recent Echini, over

TEXT-FIGS. 177-184.— Showing genital plates excluded from the periproet.

177. *Gymnechinus pulchellus* Mortensen. Gulf of Siam. Diam. 15 mm. R. T. J. Coll., 863. $\times 8.2$. Genital 3 exsert by the contact of genitals 2 and 4. Oculars I, II insert, the species character (pp. 93, 120).

178. The same. Diam. 10 mm. R. T. J. Coll., 864. $\times 8.7$. Genital 4 exsert by the contact of genitals 3 and 5.

179. *Gymnechinus robillardii* (Loriol). Mauritius? Diam. 26 mm. R. T. J. Coll., 811. $\times 4.5$. Genital 3 exsert. Oculars I, II insert, the species character (p. 120).

180. *Strongylocentrotus dröbachiensis* (O. F. Müller). York Harbor, Maine. Diam. 44 mm. R. T. J. Coll., 782. $\times 2.81$. Genital 3 exsert by the contact of genitals 2 and 4, as in text-figs. 177, 179, 184.

181. The same. Chelsea Beach, Massachusetts. Diam. 3 mm. R. T. J. Coll., 880. $\times 28$. Genital 4 exsert by the contact of genitals 3 and 5 as in text-fig. 178. No genital pores (compare text-fig. 133, p. 129).

182. The same. Dumpling Island, North Haven, Maine. Diam. 50 mm. R. T. J. Coll., 866. $\times 2.7$. Genital 4 exsert by the contact of genital 5 and ocular IV (compare text-fig. 144, p. 134).

183. The same. Calderwood Island, Maine. Diam. 32 mm. R. T. J. Coll., 865. $\times 2.8$. Genital 4 exsert by the contact of genital 3 and ocular V.

184. *Toxopneustes variegatus* (Lamarek). Boca Ceiga Bay, Florida. Diam. 58 mm. R. T. J. Coll., 872. $\times 3.7$. Genital 3 exsert (p. 121).

250,000 genital plates have been examined, and the principal striking variations noted. In the 33,000 specimens of *Strongylocentrotus dröbachiensis* studied, detailed lists of the variations of genital plates were kept as a basis for determining the numerical frequency of occurrence.

Under ocular plates it is shown that there is great diversity as to whether these meet the periproct or are shut out from it. On the other hand, genital plates show great uniformity in that all the plates meet the periproct. No exception to this is known in fossil regular Echini; in Recent Echini, however, some exceptions have been found as individual variations.

Dr. Mortensen (1904, p. 114) says of *Gymnechinus pulchellus* that sometimes one of the genitals, mostly 3, is excluded from the periproct. He writes me that in about thirty percent of the specimens genital 3 and more rarely 4 is exsert. In ten selected specimens of *G. pulchellus* that Dr. Mortensen generously sent me, four have genital 3 exsert (text-fig. 177), two have genital 4 exsert (text-fig. 178), and four have all genital plates reaching the periproct. In a specimen of *Gymnechinus robillardi* (text-fig. 179) genital 3 is exsert. De Loriol (1883) figures the same species with genital 4 exsert. In his collection I saw two specimens with genital 4 exsert, as in text-fig. 178. It is striking that this very exceptional character is common in two related species. Specimens with exsert genitals have been found in a few other species. One specimen in 139 *Microcyphus maculatus* (this is in de Loriol's collection in Geneva), one in 1,043 *Toxopneustes variegatus* (text-fig. 184), and two in 2,643 *Toxopneustes atlanticus* have genital 3 exsert. In 33,000 *Strongylocentrotus dröbachiensis* 37 specimens have genital 3 exsert (text-fig. 180). In all the cases seen of genital 3 exsert in the several species, this plate was similarly excluded by the contact of genitals 2 and 4 as figured. In *S. dröbachiensis* eight specimens have genital 4 exsert. This, however, is not excluded by the same plates in all cases. In a very young individual (text-fig. 181) genital 4 is excluded by the contact of genitals 3 and 5, as in *Gymnechinus pulchellus* (text-fig. 178). Another method of exclusion of genital 4 is by the contact of genital 5 and ocular IV (text-fig. 182); and in a third method, which may be considered more normal for the species, genital 4 is excluded by the contact of ocular V and genital 3 (text-fig. 183). In the Museum of Comparative Zoölogy, a *Microcyphus maculatus* from Mauritius has genital 4 excluded by the contact of ocular V and genital 3, as in text-fig. 183; also a *Heterocentrotus trigonarius* from the same locality has genital 3 excluded by the contact of genitals 2 and 4, as in text-fig. 184; and a *Microcyphus annulatus* Mortensen, from Bass Straits, Australia, has genital 1 excluded from the periproct by the contact of genitals 5 and 2. The oculars of this specimen are all exsert, as usual in the genus.

In all, 61 cases have been seen in 50,000 specimens with a genital excluded from the periproct, 47 of the cases being of genital 3, thirteen of genital 4, and one case of genital 1. Why genital 3 or 4 should be excluded and almost no others is not obvious, but it shows how definite even a very rare variation can be.

While genitals are rarely excluded from the periproct as variants, they are still more con-

stantly in contact with the interambulacrum ventrally. In *Bothriocidaris archaica* (Plate 1, fig. 2) the genitals lie wholly dorsal to the oculars, and in *B. pahleni* (Plate 1, fig. 6) they do so in part. In one specimen of *Strongylocentrotus dröbachiensis* (Plate 5, fig. 16) genital 1 lies dorsal to the oculars, as in *Bothriocidaris archaica*; but in this peculiar specimen interambulacrum 1 is wanting (p. 42), which accounts for this exceptional genital exclusion. Otherwise, as far as seen, a genital, when existent, always extends to the interambulacrum of its area.

Genital plates are of secondary importance. One may be absent without visibly affecting the corona (spatangoids, text-figs. 174, 175, p. 149). Rarely a genital may be wanting in regular Echini (p. 45), when the other portions of the test have the usual pentamerous system. Such a case is seen in *Eucidaris* (text-fig. 185). In this specimen there are five oculars, I and II being in contact from the absence of genital 1. In interambulacrum 1 there are two young plates lying against oculars I and II; the next older plate belonging to column 2 is large and

extends across the area, whereas the third older plate is small. Otherwise the corona is quite as usual. In two specimens of *Arbacia* (Plate 4, figs. 11, 12) and in a *Strongylocentrotus* (Plate 6, fig. 7), genital 4 is wanting and interambulacrum 4 is narrowed, consisting in part of only a single column of plates. In *Tripneustes esculentus* (Plate 6, fig. 4) there are six oculars, but no additional genital, so that the extra genital may theoretically be considered as wanting, and there is only a single column of interambulacral plates throughout the added area as far as developed. In all of these specimens in the area where the genital is wanting, the interambulacrum dorsally abuts against the two overlying ocular plates in a similar manner to that of *Bothriocidaris* and the posterior area in spatangoids (text-figs. 162, 174, 175 p. 149).

185

TEXT-FIG. 185.—*Eucidaris tribuloides* (Lamarck). Jamaica. Diam. 34 mm. R. T. J. Coll., 802. Genital 1 wanting. Young interambulacral plates originate against oculars I and II, as usual (p. 45).

Genital and ocular plates are fused in a mass in clypeastroids, and two genitals may be fused in spatangoids (A. Agassiz, 1904, p. 161), but in regular Echini these plates are typically separate. Occasionally, however, in regular Echini two genitals or a genital and an ocular are fused. In a specimen of *Centrechinus setosus* (text-fig. 186) genitals 2, 3 and ocular III are fused into a perfectly symmetrical mass, no trace of sutures being visible. A similar fusion of two genitals, or a genital and an ocular, has been seen in many cases in the Echinidae and Strongylocentrotidae. In *Strongylocentrotus dröbachiensis* genitals 2, 3 were fused in 36 cases; 3, 4 in 32 cases (text-fig. 195); 4, 5 in 68 cases (text-fig. 147, p. 134); and 5, 1 were fused in 19 cases (text-fig. 148, p. 134). Genitals 1, 2 were fused in only five cases. The fusion of genitals

was seen in other species also, as *Tripneustes esculentus* (text-fig. 196). In 103 cases of *S. dröbachiensis* an ocular was fused with a genital (text-fig. 143, p. 134), any ocular of the five fusing with one or rarely two of the associated genitals. As far as the fusion of genitals, or genitals with an ocular goes, it may be considered a parallel variation to the typical condition in certain irregular Echini, where such fusion normally occurs.

While fusion of genitals is rare, splitting on lines of solution to make divided plates is more common. This splitting of genitals by secondary sutures is a typical character in the Echinothuriidae only (*Asthenosoma*, text-fig. 101, p. 109, and *Phormosoma*, text-fig. 170, p. 149). Such splitting is shown fully by Mr. Agassiz (1904) in many of this family. The splitting is

TEXT-FIGS. 186-189.— Fusion, or splitting of genital plates in *Centrechinus setosus* (Leske).

186. Jamaica. Diam. 49 mm. R. T. J. Coll., 803. $\times 2.8$. Genitals 2, 3 and ocular III are fused in a mass; oculars I, V, IV, II insert, bilaterally symmetrical through III, 5.

187. Bahamas. Diam. 85 mm. R. T. J. Coll., 714. $\times 2.8$. Genitals split by secondary sutures.

188. Bahamas. Diam. 85 mm. R. T. J. Coll., 689. $\times 2.8$. Madreporic pores in genitals 2, 3, and ocular III.

189. Jamaica. Diam. 71 mm. R. T. J. Coll., 772. $\times 2.8$. Madreporite split by secondary sutures.

especially marked on the ventral border of genital plates or may pass directly through the plate. I have seen no splitting of genitals in fossil Echini, but it is rather common as a variant in Recent species. Such secondary division of genitals is seen in *Centrechinus* (text-figs. 187, 189).

In *Strongylocentrotus dröbachiensis* many cases of split genitals were found. In 275 cases genital 3 is split by a transverse suture parallel to the base, as in text-fig. 190. This seems to be a family peculiarity, as it was observed in several species of the Echinidae as in *Tripneustes esculentus* (Plate 6, fig. 4), and in the Strongylocentrotidae. Instead of splitting by one transverse suture, as in text-fig. 190, genital 3 may be divided by one or more sutures in other planes, as in text-fig. 190a and 190b; such were noted in 90 cases. Genital 3 is split much more

TEXT-FIGS. 190-196.— Splitting, fusion, etc., of genital and ocular plates, in *Strongylocentrotus* and *Tripneustes* (p. 28).

190. *Strongylocentrotus dröbachiensis* (O. F. Müller). York Harbor, Maine. Diam. 54 mm. R. T. J. Coll., 773. $\times 3$. Genital 3 split by one horizontal suture (compare Plate 6, fig. 4).

190a. The same. Diam. 38 mm. R. T. J. Coll., 774. $\times 3$. Genital 3 split by one vertical suture.

190b. The same. Diam. 49 mm. R. T. J. Coll., 775. $\times 3$. Genital 3 split by three sutures.

191. The same. Calderwood Island, Maine. Diam. 46 mm. R. T. J. Coll., 879. $\times 3$. Genital 2 split.

192. The same. Harpswell, Maine. Diam. 43 mm. R. T. J. Coll., 776. $\times 3$. Several genitals split by secondary sutures.

193. The same. York Harbor, Maine. Diam. 46 mm. R. T. J. Coll., 711. $\times 4$. Genitals 2, 3, and oculars III, V are split by secondary sutures; the splitting of oculars is a very rare variation (Plate 6, fig. 6).

194. The same. Diam. 42 mm. R. T. J. Coll., 700. $\times 4$. Genitals 1 and 2 much split up; ocular V split; extra genital pores, but there is no genital pore in the madreporite (compare text-figs. 197-199, p. 171).

195. The same. Diam. 41 mm. R. T. J. Coll., 777. $\times 3$. Genitals 3, 4 fused (compare Plate 6, fig. 2; Plate 7, fig. 7).

196. *Tripneustes esculentus* (Leske). Bermuda. Diam. 138 mm. R. T. J. Coll., 787. $\times 2$. Genitals 5, 1 fused; oculars V, IV, II insert (pp. 93, 124).

frequently than any other plate in the families of the Echinidae and Strongylocentrotidae. Genital 2 is also frequently divided in *S. dröbachiensis* by secondary sutures (text-figs. 191-194.) Divisions of this plate were found in 120 cases in this species. Genitals 1, 4, and 5 are occasionally divided by secondary sutures, as seen in 134 cases, but 2 and 3 take the lead by a strong majority. Very rarely oculars are split (text-figs. 193, 194), but only ten cases were noted; otherwise, genitals divided by secondary sutures are the only cases I have seen in Echini of plates derived by the fission of preëxisting plates. In the young of echinothuriids, genitals are not split, and in Strongylocentrotus the splitting was very rare in young specimens, while rather frequent in adults. It is evident, as in echinothuriids, that this is a character that comes in with increasing age. Occasionally a line of secondary suture only goes partially through a plate, demonstrating that these are true cases of splitting and not cases of accessory plates.

In very young Echini genital pores do not exist, as shown fully by Lovén (1892) and A. Agassiz (1904). As seen in *Strongylocentrotus dröbachiensis* (p. 131, text-figs. 131-134), no genital pores were found in specimens up to 5 mm. in diameter, after which age they come in rapidly, and only 128 in 800 were without such pores in the series 5 to 10 mm. diameter; only six in 2,000 were without genital pores in the series 10 to 15 mm. diameter, and no larger specimen was wholly imperforate. Occasionally, one, more rarely two, and in three cases three genitals were imperforate in adults. In a fresh *Toxopneustes atlanticus* examined, in which a genital was imperforate, the corresponding genital gland was absent. The absence of a genital pore as a variant may be compared with *Holactypus* (text-fig. 171, p. 149), and some spatangoids (A. Agassiz, 1904) in which one or more genitals are typically imperforate.

Typically, in post-Palaeozoic regular Echini there is a single genital pore within the confines of each genital plate. In *Goniocidaris nutrix* and *canaliculata* (text-figs. 72-74, p. 99) the ventral border of the genitals is open, doubtless resorbed so that the genital pores impinge on the interambulacra. This character has been seen as a variant in *Centrechinus setosus*, *Arbacia nigra*, and *Strongylocentrotus dröbachiensis*, but is of uncommon occurrence. Mr. Agassiz (1873) shows that in the clypeastroid *Peronella peronii* (Agassiz) the genital pores lie in the interambulacra widely removed from their usual position. In an *Arbacia punctulata* in one area the genital pore is not in its usual plate, but passes through the third interambulacral plate from the apical disc. In Strongylocentrotus the genital pores very rarely perforate an interambulacral plate, and in four cases found perforated an ocular plate. While genital pores are usually found in genital plates, it seems that there is no necessary correlation, and the pore when developed may perforate any portion of the test.

Genital pores are usually perfectly visible in dorsal view, are even salient features, but in *Salenia pattersoni* they are invisible externally though plainly seen in an internal view of the same specimen (Plate 4, figs. 1, 2). While a single genital pore to a plate is the character in Recent regular Echini, supplementary pores are not rare. They are especially common in *Arbacia*

punctulata (text-figs. 197, 198), in which I previously described them (Jackson, 1899, p. 130). Similar extra genital pores have been seen in *Eucidaris tribuloides*, *Echinus affinis* (text-fig. 115), *Strongylocentrotus franciscanus* (text-fig. 199), *S. dröbachiensis* (text-fig. 193), and many other species. In *S. dröbachiensis* extra pores were seen in 186 specimens. Dr. Mortensen writes me that such extra pores are connected with the genital glands. They are always sporadic

TEXT-FIGS. 197-199.—Extra pores in genital plates.

197. *Arbacia punctulata* (Lamarck). Woods Hole, Massachusetts. Diam. 34 mm. R. T. J. Coll., 656. $\times 3$. All oculars exsert.

198. The same. Diam. 35 mm. R. T. J. Coll., 655. $\times 3$. Ocular V insert (p. 115).

199. *Strongylocentrotus franciscanus* A. Agassiz. California. Diam. 123 mm. R. T. J. Coll., 726. $\times 2$. Oculars I, V insert (compare text-fig. 115, p. 117).

and apparently may be considered a parallel variation to, rather than a genetic connection with, the Palaeozoic types where extra pores typically occur.

In the Ordovician *Bothriocidaris* (Plate 1, fig. 2) genital pores are unknown; it may be that they were wanting, as such pores are wanting in young Echini. More likely they existed but do not show in external view, as noted in *Salenia pattersoni* (p. 112). In an ancient fossil it would be easy for small genital and madreporic pores to be so filled up as not to be recognizable, for frequently in fossils pores cannot be seen when we know from other specimens that such existed. In *Lepidechinus* (Plate 63, figs. 7, 8) there is one pore in each genital plate in the only species of the genus in which the apical disc is known.

In other Palaeozoic Echini genital plates typically have more than one pore to a plate. There may be two or three, as in *Lepidesthes* (Plate 68, fig. 5), or there may be three to five in a plate, as in *Palaeochinus* (Plate 29, fig. 6; Plate 30, fig. 4), *Lovenechinus* (Plate 41, fig. 3), and *Melonechinus* (Plate 56, fig. 6). Instead of a few pores there may be numerous genital pores to a plate, even as many as ten or eleven, as shown in *Lepidocentrus* (Plate 21, fig. 5), *Pholidechinus* (Plate 28, fig. 10), and *Perischocidaris* (Plate 67, fig. 3). It is possible that in types where fine madreporic pores are unknown, some of the larger pores served as madreporic

openings. Otherwise all the pores in genital plates doubtless connected with genital glands, as in Recent Echini with accessory pores.

In very young Recent Echini, as shown by Lovén (1892), there is a single madreporic opening in genital 2 (Plate 2, fig. 3; Plate 3, fig. 14; text-fig. 131, p. 129). Fine madreporic pores soon appear, and in the adult are usually numerous (*Strongylocentrotus*, text-figs. 132-139, p. 132). In some types there are few madreporic pores in the adult, a primitive character (*Salenia*, Plate 4, fig. 1). Usually the madreporite is perforated by many pores, as seen from the interior as well as from the exterior. In the Cidaridae, however (text-figs. 59, 60; 70, 71, pp. 95, 98), while there are many on the exterior of the plate, there is only a single large madreporic pore on the interior, so that at this part of the plate the youthful character is retained in the adult. The same condition exists in *Salenia pattersoni* (Plate 4, figs. 1, 2). In *Echinocyamus* (Lovén, 1874) there is a single external madreporic pore. In *Habrocidaris scutata* (text-fig. 206), as shown by Messrs. A. Agassiz and Clark (1908), no fine madreporic pores exist in genital 2, but, instead, there is a single pore in the middle of the plate, which appears to be a retention in the adult of the single madreporic opening characteristic of the young. This is the only case known in an adult regular echinoid.

In Palaeozoic Echini a typical madreporite with numerous fine pores is known in a few species. It exists in *Lovenechinus lacazei*, as observed by Bather (text-fig. 243); also, it has been found in *Lepidesthes formosa* (Plate 68, fig. 5), *L. colletti* (Plate 71, fig. 1), *Meekechinus elegans* (Plate 76, fig. 6), and *Echinocystites pomum* (Plate 18, fig. 6). In a number of Palaeozoic genera the apical disc is not known well enough to enable one to state anything with assurance. In the Palaeoechinidae the apical disc is known in many species and yet the madreporite has been seen in *Lovenechinus* only, as above noted, and reported in *Melonechinus multiporus* by Keyes (1894). I have not seen a specimen of *Melonechinus* with madreporic pores.

In post-Palaeozoic regular Echini the madreporic pores exist in genital 2, and are typically limited to that plate. In examining large series of specimens, it is frequently found that the madreporic pores extend beyond genital 2. When this occurs, in the great majority of such variants, they extend to genital 3 and frequently ocular III as well (*Centrechinus*, text-fig. 188); or they may extend to ocular III without invading genital 3 (text-fig. 146, p. 134). This extension of madreporic pores has been seen in many species, but in *Strongylocentrotus dröbachiensis*, on account of the number examined, a greater range is known than in others studied. Of this species in 33,000 specimens, 928 cases were noted in which madreporic pores extended from genital 2 to 3 (Plate 5, fig. 13). In 128 cases madreporic pores occur in genital 2 and ocular III (text-fig. 146, p. 134), and in 64 cases in genitals 2, 3 and ocular III, as in *Centrechinus* (text-fig. 188). In 80 cases, madreporic pores are in genitals 1, 2, 3, and in 60 cases in genitals 2 and 1 (text-fig. 142, p. 134). Other variations in the extension of madreporic pores beyond genital 2 are only rarely found. In 15 cases, they exist in genital 2 and ocular II; in

six cases in 2, III, II; in three cases in 2, 3, III, and II; in four cases in 2, 3, II (text-fig. 148, p. 134). In seven cases madreporic pores occur in genitals 1, 2, 3, and ocular III; in four in 1, 2, 3, and II; and in eleven in 1, 2, 3, and II, III (Plate 5, fig. 14). The most extreme range observed was one specimen in which the madreporic pores extended from genital 2 to genitals 1, 3, 4, and oculars III, IV, V. A similar range of variation in the distribution of madreporic pores and in about the same proportions has been found in other species, especially in the families Echinidae and Strongylocentrotidae. In the young, madreporic pores very rarely extend beyond genital 2, whereas they frequently do in the adult. This change evidently is taken on as the animal increases in size to the adult condition.

Occasionally madreporic pores invade interambulacrum 2, and in one somewhat distorted *Strongylocentrotus dröbachiensis* this invasion was extensive. All this goes to show that while typically madreporic pores are limited to genital 2, they may extend from this plate to adjacent genitals, oculars, or interambulacrum, but apparently never to plates of the periproct. They seem never to be absent from genital 2 in Recent regular Echini. When madreporic pores extend beyond genital 2, in the great proportion of cases they move to the left of the antero-posterior axis, emphasizing by this a bilateral axis or plane of symmetry through III, 5.

As seen from these studies, the genital plates have nothing to do with the interambulacrum, which develops on either side of the oculars (p. 62). The genitals typically possess genital pores, and one of them possesses madreporic pores, but both of these structures may pierce other parts of the test. Genital plates may, therefore, be considered as structures of secondary importance, of much less morphological value than are the oculars.

THE PERIPROCT.

The periproct is an area of considerable interest. Unfortunately in fossils it is rarely preserved, as the plates easily drop out and are frequently wanting, even in museum specimens of Recent Echini. It is worth noting that in Recent Echini periprocts and peristomes may be rendered strong and safely fastened in place by dipping the specimens in dilute shellac dissolved in alcohol, or gelatine dissolved in water. The same treatment is very effective in strengthening the thin tests of delicate Echini and in keeping the spines firmly in place.

In Palaeozoic Echini the plates of the periproct are small, angular, and completely fill the area, as in cidarids. In *Bothriocidaris archaica* there are nine small plates that fill the area dorsal to the genitals (Plate 1, fig. 2). In *Hyattcechinus beccheri* (Plate 25, fig. 5) a few periproctal plates are preserved (others restored in the figure), indicating a periproct essentially as in Cidaris. In *Palaecechinus* (Plate 31, fig. 4), *Maccoya* (Plate 34, fig. 6), *Lovenechinus* (Plate 42, fig. 6), and *Melonechinus* (Plate 56, fig. 1) the periprocts as far as preserved are made up of many polygonal, rather thick plates filling the area, that are essentially like those of

Eucidaris tribuloides in structure (text-figs. 62-69, p. 98). In the Lepidesthidae, the periproctal plates in the known types are essentially the same, like cidarids, but are rather thinner and more scale-like; such are shown in *Lepidesthes formosa* (Plate 68, fig. 5), *L. colletti* (Plate 71, fig. 1), and *Meekechinus elegans* (Plate 76, fig. 6). Palaeozoic types as far as known do not throw any light on the suranal plate, which is such a prominent feature in the young of some Recent Echini and the adults of certain genera. There is no evidence that a suranal plate was differentiated in the Palaeozoic, and, as it is apparently wanting in the Cidaroida and Aulodonta, both young and adult, it is also doubtless wanting in the Palaeozoic.

In the Cidaroida, periproctal plates are thick and angular, filling the area, with the anus central. They are essentially like those known in the Palaeozoic and in so far may be considered primitive. These plates are shown in representative cidarids in text-figs. 59-74, 164 (pp. 94-99, 149). Lovén (1892) figures a young *Goniocidarid* with a single plate filling the periproct (Plate 2, fig. 3); but Mortensen (1911) thinks this a mistake, as in a specimen of a similar stage he found three plates. Mr. Agassiz's (1904) figures of young cidarids, and those young specimens which I have studied, show no indication of a dominance of a first, over later added plates. It seems, then, that we have here no suranal such as exists in the Saleniidae and in young Echinidae and Strongylocentrotidae, in which groups alone has it been demonstrated. The existence of a suranal plate is apparently a secondary and specialized rather than a primitive character. Dr. Mortensen wrote me in effect that he concurs in this view, and he expresses the same in a recently published paper (1911).

In the Centrechinoida the character of periproctal plates presents wide differences in various genera. Of the Aulodonta there are large plates on the periphery of the periproct with small isolated plates within, as seen in *Chaetodiadema*, *Centrostephanus*, *Astropyga* (text-figs. 96-99, pp. 108, 109), or young *Centrechinus* (text-fig. 88); or there may be small, isolated plates only, with tissue largely leathery, as in adult *Centrechinus* (text-figs. 93-95, p. 107). Of the Stirodonta in *Salenia* and *Salenocidarid* (Plate 4, figs. 1, 6; text-fig. 102, p. 111) we find a prominent suranal plate lying dorsal to genital 3 and with small anal plates in addition. In the fossil *Peltastes* (Plate 4, fig. 7) the suranal occupies a prominent place but lies dorsal to ocular III, thus differing from *Salenia* and young *Strongylocentrotus* and *Echinus*, in which the suranal lies dorsal to genital 3. In a series of 74 specimens of *Peltastes wrighti* one specimen has two large plates, as in *Acrosalenia hemicydaroides* (text-fig. 104, p. 111), and as in that figure the larger plate, which may be considered the suranal, lies against genital 3, as in *Salenia*. This is a striking difference from the other specimens, in which there is only a single plate lying dorsal to ocular III, as shown in Plate 4, fig. 7, which is the generic character.

The fact that the suranal may occupy one of two positions has a certain bearing on other genera. In *Acrosalenia spinosa* (text-fig. 103, p. 111) the suranal lies dorsal to ocular III, as in *Peltastes*, but in *A. hemicydaroides* (text-fig. 104, p. 111) there are two large plates; the larger

of these two, which appears to be the suranal, lies dorsal to genital 3, as in *Salenia*. In *Acrosalenia wiltoni* (text-fig. 105, p. 111) there are four large periproctal plates besides a vacant space, doubtless for small anal plates as in *Salenia*. The largest of these four is probably the suranal and lies dorsal to ocular III, as in *Acrosalenia spinosa* and *Peltastes*.

In *Arbacia* there are typically four plates in the periproct, but as variants there may be fewer or more than this number. Bell (1879) notes that there may be as few as three or as many as ten, and Mr. Agassiz (1881, p. 57) notes that there may be more than four up to thirteen periproctal plates. I noted (1899, p. 131) that in *Arbacia punctulata* there may be as few as three or as many as nine plates as variants from the typical four. In *Arbacia* the typical four periproctal plates lie in such planes that two are in the antero-posterior axis III, 5, and two are on each side of this axis (text-figs. 111–114, p. 115; text-figs. 167, p. 149; 202). The

TEXT-FIGS. 200–206.— Variation of periproctal plates in *Arbacia* with the typical character in *Habrocidaris*.

200. *Arbacia punctulata* (Lamarek). Woods Hole, Massachusetts. Diam. 25 mm. R. T. J. Coll., 727. $\times 3$.

Only two periproctal plates; suranal dorsal to genital 3.

201. The same. Diam. 45 mm. R. T. J. Coll., 728. $\times 3$. Only three periproctal plates.

202. The same. Diam. 47 mm. R. T. J. Coll., 729. $\times 3$. Four periproctal plates, the typical character (p. 115.)

203. The same. Diam. 31 mm. R. T. J. Coll., 730. $\times 3$. Five periproctal plates; compare text-fig. 206.

204. The same. Diam. 36 mm. R. T. J. Coll., 731. $\times 3$. Six periproctal plates.

205. The same. Diam. 43 mm. R. T. J. Coll., 732. $\times 3$. Many periproctal plates.

205a. The same. Florida. Diam. 32 mm. R. T. J. Coll., 890. $\times 4$. One large and about fifty small periproctal plates. The specimen is so distorted its ocular arrangement is omitted in tabulation of the species, pp. 115, 153.

206. *Habrocidaris scutata* (A. Agassiz). Santa Cruz, West Indies. Diam. 17.5 mm. Adapted from A. Agassiz and Clark, 1908, Plate 54, fig. 5. $\times 3$. Five periproctal plates; compare text-fig. 203. There is only a single madreporic pore in genital 2 (compare Plate 3, fig. 14). The genital pores lie very far dorsally (p. 172).

plate lying dorsal to ocular III is apparently the equivalent of the suranal, as in *Acrosalenia willoni* (text-fig. 105), which also has four large plates. In examining some 2,300 specimens of *Arbacia punctulata*, considerable variation was found in the periproctal plates, and they varied in adults from two to many (text-figs. 200-205). Two specimens were found with only two plates and many with three. In both of these forms what I take to be the suranal overlaid genital 3, as in *Salenia*, not ocular III as usual. A number of specimens were found with five plates and several with more than five, one being shown with six and one with thirteen (text-figs. 204, 205). In one abnormal specimen from Florida (text-fig. 205a) there is one large periproctal plate facing ocular III, as usual, and, in addition, some fifty small rounded periproctal plates of a character similar to those usual in the Echinidae. When there are five periproctal plates in *Arbacia*, as in text-fig. 203, the condition is exactly like that of *Habrocidaris* (text-fig. 206). In *Parasalenia gratiosa* A. Agassiz, as shown by Mr. Agassiz (1873, p. 435), there are four periproctal plates, as in *Arbacia*, but they lie in a different plane so that two are on each side of the antero-posterior axis through III, 5. Of five specimens of *Parasalenia gratiosa* seen in de Loriol's collection, in the Geneva Museum, four have the typical four plates in the periproct, but one has only three. Variations of periproctal plates in *Arbacia dufresni* were also noted as described, p. 115.

In the young of the Echinidae and Strongylocentrotidae a suranal plate fills the periproct, as shown by Mr. Agassiz (1874, p. 732). This is typically developed in young *Echinus* (Plate 3, fig. 14) and *Strongylocentrotus* (text-figs. 131-134, p. 129). As the animal grows, the suranal gradually loses its prominence, new plates forming along its right posterior border and the suranal retaining while recognizable a position dorsal to genital 3. In the adult of *Strongylocentrotus dröbachiensis* a plate is often found dorsal to genital 3 somewhat larger than other periproctal plates (text-figs. 135-139, p. 132). It seems that this may be recognized as the suranal still holding a slight supremacy in size. A similar plate similarly located is frequently recognizable in other genera, as *Toxopneustes* (text-fig. 122, p. 122) and *Echinus* (text-fig. 115, p. 117), and may fairly be considered as the suranal. There is considerable individual variation, some specimens having no such larger plate at this area and others possessing one. Dr. Mortensen (1911) expresses the view that the suranal is not a primitive structure forming an essential part of echinoid morphology, but is a specialized structure found only in certain groups of Echini. I heartily agree with this view. It seems that the suranal is simply one of the plates of the periproct which has attained exceptional prominence and which in youth entirely fills this area in those families in which it is a marked feature (*Saleniidae*, *Echinidae*, *Strongylocentrotidae*).

In the adults of the *Temnopleuridae*, *Echinidae*, *Strongylocentrotidae*, and *Echinometridae* (text-figs. 115-161) the periproctal plates are usually relatively large and solid, more or less numerous, but not definitely limited to a small number (except in *Genocidaris* and *Parasalenia*),

and fill the periproctal area. In irregular Echini periproctal plates are relatively numerous and always fill the area completely. As clearly shown by Mortensen (1907, Plate 13) in *Brisaster* (*Schizaster*) *fragilis*, the periproct in the very young individuals is within the apical disc, as in regular Echini. It early travels out and soon assumes its adult position in the posterior interambulacrum.

In regular Echini the periproct is typically enclosed by a ring of genital, or genital and ocular plates. In the Echinothuriidae, on account of the separation of genitals and oculars, the periproct may come in contact with the interambulacra (text-fig. 170, p. 149). As a relatively rare variation, a similar condition may exist in other regular Echini, as *Strongylocentrotus gibbosus* (text-fig. 156, p. 145), *S. dröbachiensis* (Plate 5, fig. 15), and *S. lividus* (Plate 6, fig. 5). In such types the young interambulacral plates develop in contact with the oculars as usual, and the periproct has no relation with the interambulacra excepting that of mechanical contact (pp. 63, 110). In the Exocycloida the periproct lies in interambulacrum 5; it is therefore separated from the ocular and genital plates of the apical disc and completely surrounded by interambulacral plates.

THE ARISTOTLE'S LANTERN AND PERIGNATHIC GIRDLE.

Comparatively little has been published in regard to the Aristotle's lantern in Palaeozoic Echini. Trautschold (1868) figured complete lanterns in *Archaeocidaris rossica*, Sollas (1899a) figured a lantern in *Palaeodiscus*, and Meek and Worthen (1873) in *Lepidocidaris* in part. The lantern and its muscles in living Echini have been worked out quite fully by a number of authors, the most important being Valentin (1841), A. Agassiz (1872-'74, 1904, 1908, 1909), T. H. Stewart (1861), and Lovén (1892).

The jaws and muscles are often very inadequately or incorrectly given in text-books. For comparison with fossils, a lantern with soft parts was worked out in *Strongylocentrotus* (Plate 5) as a basis for comparison. The lantern of this genus and a number of others not previously described were studied, and are given more or less fully in the following pages. The perignathic girdle might properly be described with the lantern in the several types, but it seemed best to treat it separately (pp. 189-198).

It is believed that the structure of the lantern is of great value in systematic classification, and that the structure of its several parts presents characters that are of ordinal or subordinal value. As Dr. Mortensen pointed out (1904, p. 54), the structure of the teeth, keeled or unkeeled, is "a very important character, though it has hitherto received very little attention." Besides the teeth there are other features of value. Briefly stated, the essential points are: teeth grooved or keeled; epiphyses narrow, or wide and united by suture; the top of the pyramids, as seen when the epiphyses are removed, a smooth floor, or pitted; foramen magnum deep, or shallow; angle of outline of the lantern depressed or erect; compasses present or absent.

The lantern of *Strongylocentrotus dröbachiensis* is taken up first as a type of structure, because opportunity offered to study living material and abundant fresh specimens for dissection. The structure has not been published in this type excepting in so far as Lovén (1892) described the jaws and muscles in the young; the study has, therefore, interest from making known the structure in a common type and adds some features not previously recorded. In *Strongylocentrotus* there are five keeled teeth lying free about the mouth. The tooth is held in place by the two half-pyramids which ventrally enclose it closely by an inward extension of the base of the lateral wings (Plate 5, fig. 5). The tooth rests against the dental slide (*s. d.*) on the inner face of the pyramids. On each side the dental slide is produced dorsally as a guiding or styloid process, which in face view is seen projecting above the base of the foramen magnum (Plate 5, figs. 4, 7). After traversing freely the space of the foramen magnum, in this type the tooth rests against two guiding processes, the crests of the epiphyses (Plate 5, figs. 2-5, 7, 9). The tooth then curves inward, takes a second sharp curve on itself and in the same plane, and terminates in a free point in the dental capsule (Plate 5, fig. 6). From the mouth to a point just above the crests the tooth is calcified; beyond this point to the proximal tip the tooth is soft and pulpy and easily destroyed. In area 1 of Plate 5, fig. 9, the soft part of the tooth has been removed, whereas it is in place in areas 2 and 3. The calcified part is that usually shown in figures of lanterns, and is the only portion preserved in fossils, as in *Archaeocidaris* (Plate 12, figs. 4-8) and *Pholidechinus* (Plate 27, figs. 4-6). An entire tooth spread out flat is shown in Plate 5, fig. 8; it is seen that at the dorsal, young or growing portion of the tooth it is grooved, but, passing ventrally, the character of the keel is soon taken on. That is, the young, last added portion of the tooth as a localized stage in development is grooved, as is the whole tooth in the *Aulodonta*, *Cidaroida*, and *Palaeozoic* forms; whereas the older or earlier formed portion of the tooth has taken on the full specific and subordinal character of a keel. The pyramids are each composed of two pieces joined by a median or pyramidal suture (Plate 5, figs. 4, 7, *p. s.*), and each piece is spoken of as a half-pyramid. Dorsally the pyramid includes a wide angle, the foramen magnum, which in this and allied species is rather deep. On the inner side at the base (Plate 5, fig. 5) the wings of the pyramid curve around so as to embrace the tooth tightly at its point of exit. Each half-pyramid consists of a peripheral portion, the outer face of which gives rise to two muscles, and the inner bears one of the two dental slides which support each tooth, and a lateral wing which is strongly ridged horizontally for attachment of the interpyramidal muscles. The dorsal face of the half-pyramid, seen only when the epiphysis is removed (Plate 5, figs. 9, 10), presents a series of pits of considerable size and depth. These pits have apparently been overlooked by previous observers. They are important, as they are characteristic of the order of the *Centrechinoidea*, but are not found in other orders of *Echini*. In 100 specimens of *Strongylocentrotus dröbachiensis* from Frenchman's Bay, Maine, examined for this character, pits exist in all the pyramids, but there is considerable variation as regards the pattern and depth of the pits; occasionally they are very shallow.

An epiphysis surmounts each half-pyramid to which it is joined by close suture (Plate 5, figs. 2-7, 9). The epiphysis extends proximally, capping the half-pyramid, and laterally extends over the foramen magnum and meets its fellow of the opposite side in a median suture. Each epiphysis presents a glenoid cavity and an internal and an external tubercle (Plate 5, figs. 3, 5, 9), which serve in articulation with the brace. It also bears an elevated process or crest which is apposed to the tooth and dorsally supports that organ. The extension of the epiphyses over the foramen magnum so as to unite in suture and the crests developed on the same, are important characters seen in the four families of the Temnopleuridae, Echinidae, Strongylocentrotidae, and Echinometridae, comprising the new suborder Camarodonta, but are absent in other Echini (p. 183).

The brace is a block-shaped plate, often called rotula, which rests on and interlocks with the two opposed epiphyses (Plate 5, figs. 9, 11, 12). On its outer lateral borders it presents two condyles which fit into the glenoid cavities of the epiphyses. The compass (Plate 5, figs. 2, 9) rests on top of the brace, extends over its whole length, is attached to the brace on its inner proximal end by a tiny ligament, and is bifurcated on its outer end. Each compass consists of two parts, a suture just within the circular compass muscles separating the compass into an inner and an outer piece. The structure of the compass and brace is quite uniform in Echini, excepting the clypeastroids. There are thus forty pieces in the lantern of *Strongylocentrotus*, and in all other Echini that possess a lantern, excepting the clypeastroids. These parts are in brief: five teeth; ten half-pyramids; ten epiphyses; five braces; ten pieces making up the five compasses.

Next taking up the soft parts associated with the lantern of *Strongylocentrotus dröbachiensis*, we find that each tooth at its basal portion is enclosed in a voluminous, very delicate transparent sac that may be called the dental capsule. A dental capsule is figured by the Sarasins (1888) in *Asthenosoma*,¹ and is mentioned in *Cidaris* by T. H. Stewart (1861) and in *Echinus* by Chadwick (1900), but I think it has not been adequately shown before. In order to see the sac properly, a specimen should be opened alive, right out of the sea. It is so delicate and sensitive, that if opened a few hours later, though the animal be still active, the sac has shrunk to small proportions. In alcoholic material as far as observed it is always collapsed. When opened thus alive, the capsules are so inflated that they look like five bladders radially arranged, and so large that they actually touch one another at the area nearest the oesophagus (Plate 5, fig. 1). The sac envelops the base of the tooth completely, lies free, but on its outer border passes over the epiphyses and some distance down the face of the area of the foramen magnum (Plate 5, fig. 6). Similar capsules were seen in fresh specimens of *Arbacia punctulata*, *Sphaerechinus granularis*, and *Strongylocentrotus lividus*, and very small ones in *Echinarachnius parma*. It would be interesting to study the capsules in perfectly fresh material of other Echini.

¹ Unfortunately in Lang's (1896) copy of this figure, the dental capsule is labeled Polian vesicle.

The muscles of the lantern are very complex. They have not been described in adult *Strongylocentrotus*, though Lovén (1892) showed them in a very young one and in exquisite detail in the adult of several types. There are sixty muscles in *Strongylocentrotus* and other regular Echini. There are ten protractors (Plate 5, figs. 1, 4, *pr.*; text-fig. 229), which take origin on the upper outer face of the half-pyramids and epiphyses and are inserted at the base of the two half-interambulacra which are associated with the intervening ambulacrum (compare text-figs. 218, 219, p. 191). The protractors serve to extend the mouthparts, which the animal actively does when in good condition. The ten retractors (Plate 5, figs. 1, 4, *re.*), which serve to open the jaws, take origin on the lower outer face of the half-pyramids and are inserted on the auricles. The retractors of the two half-pyramids that are united by the interpyramidal muscle pass to the two auricles of the same ambulacrum (compare text-fig. 219, p. 191). Ten radial compass muscles take origin from the bifurcated termini of the compasses and are inserted at the base of the two next adjacent half-interambulacral areas. From studying their motions in life, and from their position and wide divergence, it seems that the function of the radial compass muscles is to maintain and restore the vertical position of the lantern. When alive, the mouth with the peristome is freely and actively extended and retracted, and not in a vertical plane only, but with much sidewise or inclined motion, so that the radial compass muscles are in just the position to effect the motion and restore the perpendicular. It is noteworthy that in clypeastroids, where the lantern is in almost immediate contact with the base of the test and little motion is possible, the protractor muscles are very small and the compasses with their muscles are absent.

The distribution of protractor, retractor, and radial compass muscles is immediately connected with the view expressed (pp. 62, 190), that the corona may be considered as made up of five rather than ten areas. Five large but short interpyramidal muscles (Plate 5, fig. 2, *ip.*), extend from the corrugated lateral wing of each half-pyramid to the similar wing of the next adjacent half-pyramid. These muscles serve to close the jaws and from their size must be very powerful. Ten tiny internal brace muscles (Plate 5, fig. 12, *i. b.*) extend from the brace to the two associated epiphyses, and ten similar external brace muscles, (*e. b.*), extend also from the brace to the epiphyses, binding these parts together and doubtless giving some mobility. Five circular compass muscles (Plate 5, fig. 1, *i.*) extend between the compasses, being inserted at the proximal end of the outer of the two pieces of which each compass is composed. Their function is not evident.

In brief the sixty lantern muscles of *Strongylocentrotus* and other regular Echini are as follows: ten protractors; ten retractors; five interpyramidal muscles; ten internal brace muscles; ten external brace muscles; five circular compass muscles; ten radial compass muscles.

Such being the character of the lantern of the adult, it is important to see what is the

character in the young. Lovén (1892, p. 13, Plate 4) described the lantern of a young *Strongylocentrotus dröbachiensis* only 1.2 mm. in diameter. At this stage the pyramids are wide-angled, so that the whole lantern is broadly inclined instead of being nearly perpendicular, as in the adult; also the sides of the half-pyramids bearing the interpyramidal muscles are curved instead of being in a nearly vertical plane as in the adult, and as a result the interpyramidal muscles are relatively longer than in the adult. In these several characters the lantern of young *Strongylocentrotus* point for point agrees with the typical Palaeozoic lantern as seen in *Archaeocidaris* (Plate 12, figs. 4-6) and *Pholidechinus* (Plate 27, figs. 4-6). The same agreement with the Palaeozoic characters is seen in the lantern of young *Goniocidaris* (Plate 2, fig. 17).

Having considered the lantern and muscles of *Strongylocentrotus*, representative lanterns of Echini will be taken up in the sequence of their structural differentiation. Of *Bothriocidaris* nothing is known but the tips of the teeth, or pyramids. They lie opposite the ambulacra (Plate 1, fig. 1). That they occupy this anomalous position is without explanation unless by an accidental twist they have come to assume it. It is the most ambiguous feature of this important type.

I have been so fortunate as to secure for study some excellent lanterns of Palaeozoic genera. These are described under their several species, but are briefly considered here. The essential character of the lantern in the Echinocystoidea and Perischoechinoidea is represented by *Archaeocidaris* (Plate 12) and *Pholidechinus* (Plate 27); other genera as far as known present only slight differences. Of other genera it is known more or less completely in *Palaeodiscus*, *Oligoporus* (Plate 50, figs. 11, 12), *Melonechinus* (Plate 56, figs. 9, 10), *Lepidesthes* (Plate 68, figs. 9-14), *Pholidocidaris* (Plate 74, figs. 2, 6, 7), and *Meekechinus* (Plate 76, fig. 7). In the Palaeozoic genera the teeth are grooved, and when in place, extend slightly above the base of the foramen magnum (*Pholidechinus*, text-fig. 207, Plate 27, figs. 5, 6). While the teeth are usually obtusely acuminate orally, as in *Pholidechinus* and *Lepidesthes* (Plate 68, fig. 9), in one genus, *Meekechinus* (Plate 76, fig. 7), the teeth are deeply serrate distally, a unique character. The pyramids are wide-angled in outline and as a result the lantern is inclined at an angle of about 45 degrees instead of being nearly perpendicular as in the adults of most living regular Echini; also the lateral wings of the pyramids are curved, indicating quite long interpyramidal muscles (Plate 27, figs. 4, 6). In these characters the Palaeozoic lantern approaches closely that in the young of modern types (*Goniocidaris*, Plate 2, fig. 17), and also the adult of Recent echinothuriids (Plate 2, figs. 19-21). The foramen magnum is moderately deep (*Archaeocidaris*, text-fig. 208, Plate 12, fig. 4). It appears very shallow in *Pholidechinus* (Plate 27, fig. 6), but this is in part due to the position in which the specimen was drawn. The lateral wings of the pyramids present a corrugated surface for attachment of interpyramidal muscles (Plate 12, fig. 8; Plate 13, fig. 13; Plate 68, fig. 12). The dorsal surface of the half-pyramids, seen when the epiphyses are removed, is smooth, as in the Cidaroida

(Plate 2, fig. 9), not pitted as in the Centrechinoida. The half-pyramid seen from within shows a dental slide for the support of the tooth (Plate 13, fig. 14; Plate 50, fig. 12), as in Recent Echini. The styloid processes do not extend above the base of the foramen magnum, in this feature being like the Cidaroida, but unlike the Centrechinoida, where the styloid processes are visible in face view (text-fig. 211). The epiphyses cap the half-pyramids and are narrow, projecting only slightly beyond the limits of the outline of the half-pyramids (text-figs. 207, 208; Plate 12, figs. 1, 7; Plate 27, figs. 4-6). Each epiphysis possesses a glenoid cavity for the interlocking of the brace (Plate 12, fig. 8; Plate 68, fig. 12). The brace is a block-shaped plate, practically identical with that of living regular Echini. It rests on the epiphyses, and its condyles fit into their glenoid cavities (Plate 12, figs. 3, 6, 7; Plate 27, figs. 4-6). A compass is such a delicate structure that it is rarely preserved, but one was found in *Archaeocidaris* (Plate 12, figs. 1, 2) resting on the brace and with the typical bifid outer end. A compass is also shown in *Pholidechinus* (Plate 27, fig. 5), but the bifid end is gone, or possibly it did not have such a bifurcation, as it is not existent in all Recent compasses. These are the first cases of compasses described from Palaeozoic species.

It is seen that in the Palaeozoic Echinocystoida and Perischoechinoida the lantern is made up of forty pieces, as in Recent regular Echini. In structure it approaches closest to that of *Cidaris*. There were doubtless the same sixty muscles as described in *Strongylocentrotus*. It is interesting to see how near the characters of these ancient genera are to those of living forms, and also that their closest comparison is with the young of the latter.

In the Cidaroida the lantern is the most primitive of any Recent Echini. Lovén (1892) showed the character in the young of *Goniocidaris*; here at a very early stage the pyramids are very wide-angled, with long interpyramidal muscles and a deep foramen magnum (text-fig. 209; Plate 2, fig. 17). In these characters it differs from the adult, but is practically identical with the Perischoechinoida. According to Lovén, at this early stage the protractor and retractor muscles are inserted directly on the primordial interambulacral plates, which are still in place. This condition again by inference is close to that in the Palaeozoic genera where (excepting *Miocidaris*) apophyses and auricles are apparently always absent, and the protractor and retractor muscles were without doubt attached directly to the basicoronal interambulacral plates (text-fig. 221, p. 193).

Lovén (1892) described the lantern and muscles of "*Cidaris papillata*" (*Cidaris cidaris* (Linné)) with his usual care. To show another type and to bring out certain points, the lantern of *Eucidaris tribuloides* is here shown in text-fig. 210 and Plate 2, figs. 7-16. In this species the teeth are grooved and extend far beyond the pyramids ventrally (Plate 2, figs. 7, 8). The tooth rests against dental slides on the inner face of the pyramids, but the styloid processes are slight and do not extend above the foramen magnum so as to be seen in face view (Plate 2, fig. 10), as they do in the Centrechinoida. The pyramids are comparatively narrow-angled, stand-

ing erect, and the foramen magnum is extremely shallow, the pyramidal suture extending nearly the length of the outer face (Plate 2, figs. 8, 10). The pyramid has the usual corrugations on the lateral wings (Plate 2, fig. 7). When the epiphyses are removed, the dorsal faces of the pyramids present a smooth surface (Plate 2, fig. 9, area II). This is an important character in which it resembles Palaeozoic genera, but differs from the Centrechinoida in which pits typically occur in this area. The epiphyses are narrow, extending only slightly beyond the upper face of the half-pyramids. Each presents a glenoid cavity and internal and external tubercles for articulation with the brace (Plate 2, figs. 7, 9, 14, 15). The brace is of the usual shape with rather strongly marked condyles and external and internal foramina for articulation with the glenoid cavities and tubercles of the epiphyses. Each ossicle of the compass is composed of two pieces and is strongly arched, with a bifid outer end (Plate 2, fig. 12). A lantern is shown on Plate 2, fig. 9, drawn to give the full characters from the dorsal view. In area I all the parts are in place; in V the compass is removed to show the brace; in IV the compass and brace are removed to show the epiphyses; and in area II the epiphyses also are removed, so as to show the dorsal face of the half-pyramids. This figure may be compared with similar drawings of *Phormosoma* (Plate 2, fig. 20), *Salenia* (Plate 4, fig. 4), and *Strongylocentrotus* (Plate 5, fig. 9). These figures bring out essential differences in their several separate groups. The lantern of *Eucidaris* as shown has the character of its order and is essentially similar to that of the *Perischoechinoida*. The chief differences are the angles of the pyramid and the shallow foramen magnum. These differences, however, are bridged by the young.

In the *Centrechinoida* the structure of the lantern is extremely interesting and affords data for grouping the families in three distinct suborders on the basis of the characters of the teeth and the epiphyses. The order as a whole differs from other orders in that the dorsal face of the half-pyramids (seen when the epiphyses are removed) shows a series of pits instead of plane surfaces. The order is characterized by having a deep foramen magnum instead of a very shallow one, as in the *Cidaroida*, or a moderately deep one, as in the *Perischoechinoida*.

The first suborder, which I would call the *Aulodonta*, (*αὐλός*, a groove, and *ὀδούς*, tooth) is characterized by grooved teeth and narrow epiphyses, not meeting in suture over the foramen magnum (*Centrechinus*, text-fig. 211; *Phormosoma*, Plate 2, figs. 19-21). The second suborder or *Stirodonta* (*στειρά*, a keel, and *ὀδούς*, tooth) is characterized by keeled teeth and narrow epiphyses, not meeting in suture over the foramen magnum (*Salenia*, Plate 4, figs. 3, 4; *Glyptocidaris*; *Stomopneustes*, Plate 4, figs. 8-10; *Arbacia*, text-fig. 212). The third suborder or *Camarodonta* (*καμάρα*, anything with an arched covering, and *ὀδούς*, tooth) is characterized by keeled teeth and wide epiphyses, meeting in suture over the foramen magnum (*Tripneustes*, text-fig. 213; *Strongylocentrotus*, Plate 5, figs. 1-12). A more detailed consideration of these suborders and their characters follows.

Aulodonta.—In *Centrechinus setosus* (text-fig. 211, text-figs. 219, 220, p. 191) the teeth

TEXT-FIGS. 207-216.— Essential features of the lantern in representative Echini. In each species figured are shown a pyramid with associated parts in place seen in face view, with a cross section of the tooth; also an epiphysis (*A*) seen from above, and a top view of a half-pyramid (*B*) from which the epiphysis has been removed.

207. *Pholidechinus brauni* sp. nov. Lower Carboniferous, Crawfordsville, Indiana. Yale University Museum Coll., 321. $\times 3.4$. (Compare Plate 27.) Tip of compass restored as indicated by dotted lines. Tooth grooved and epiphyses narrow, foramen magnum moderately deep.

208. *Archaeocidaris rossica* (Buch). Lower Carboniferous, Miatschkowa, Province of Moscow, Russia. Mus. Comp. Zool. Coll., 3, 181. $\times 3.2$. (Compare Plate 12.) Top of pyramid smooth, tooth grooved, epiphyses narrow, foramen magnum moderately deep. Tip of the tooth restored as indicated by dotted lines.

209. *Goniocidaris canaliculata* A. Agassiz. (Adapted from Plate 2, fig. 17.) Young lantern, epiphyses narrow, foramen magnum moderately deep.

210. *Eucidaris tribuloides* (Lamarck). Bahamas. R. T. J. Coll., 694. $\times 3.2$. Top of pyramid smooth, tooth grooved, epiphyses narrow, foramen magnum very shallow. (Compare text-fig. 218, p. 191; Plate 2, figs 7-16.)

211. *Centrocchinus setosus* (Leske). Bermuda. R. T. J. Coll., 788. $\times 1.6$. Top of pyramid pitted, tooth grooved, epiphyses narrow, foramen magnum deep (compare text-figs. 219, 220, p. 191).

212. *Arbacia punctulata* (Lamarek). Woods Hole, Massachusetts. R. T. J. Coll., 883. $\times 4$. Top of pyramid pitted, tooth keeled, epiphyses narrow, foramen magnum deep.

213. *Tripneustes esculentus* (Leske). Florida. R. T. J. Coll., 884. $\times 2.4$. Top of pyramid pitted, tooth keeled, epiphyses wide, meeting in suture with crests supporting tooth, foramen magnum deep (compare Plate 5, figs. 1-12).

214. *Clypeaster rosaccus* (Linné). Bahamas. R. T. J. Coll., 885. $\times 1.6$. Top of pyramid smooth, pyramids laterally flaring, epiphyses narrow, compass wanting, foramen magnum very shallow.

215. The same. Tooth keeled, in side and face views and in section.

216. The same. Revolved outward to show ventral tip of tooth.

Text-figs. 207-209, pyramid wide-angled, lantern inclined; 210-213, pyramid narrow-angled, lantern erect; 214, pyramid flaring, lantern procumbent.

Lettering: *b*, brace; *c*, compass; *er.*, crest; *ep.*, epiphysis, top view and in place; *f*, foramen magnum; *p*, top of pyramid; *sl.*, styloid process; *t*, tooth.

are grooved and continue calcified high above the base of the foramen magnum. They are supported by the dental slides, as usual, and the long styloid processes, typical of the order, are a prominent feature in face view. The pyramids are narrow-angled, with a deep foramen magnum, and the upper borders of the pyramids curve inward over the space of the foramen magnum and a slight distance beyond the epiphyses. The top of the pyramids has deep pits seen when the epiphyses are removed (text-fig. 211*B*). The epiphyses are narrow, not quite covering the dorsal face of the half-pyramids. The brace and compass are as usual except that the compass may be outwardly rounded instead of bifid as in most Echini. In text-fig. 219 (p. 191), the protractor and radial compass muscles are shown passing from the lantern to the two half-interambulacra associated with ambulacrum III and the retractor muscles passing to the auricles that originate on ambulacrum III.

The genus *Phormosoma* is most interesting as representing the remarkable Echinothuriidae. Mr. Agassiz (1904, Plate 47) figured the structure of the lantern in *Echinostoma hispidum* (A. Agassiz), and I show it in another species, *Phormosoma placenta*. The teeth are grooved, narrowly acuminate distally (Plate 2, figs. 19-21). They are supported by the dental slides and styloid processes as usual. The pyramids are very wide-angled with long interpyramidal muscles. As the angles are wide, the lantern is inclined instead of nearly perpendicular, the usual character of the suborder, and in this respect it is closely like that in the adult of Palaeozoic and the young of Recent species. This is best seen by comparing the dorsal view of *Phormosoma* (Plate 2, fig. 20) with that of *Pholidechinus* (Plate 27, fig. 5). The foramen magnum is deep and widely curving, a very distinctive character. The dorsal face of the pyramids has the pitting seen in all the order when the epiphyses are removed, as shown in Plate 2, fig. 20, area II. In side view (Plate 2, fig. 21) the lateral wing of the pyramid is corrugated as usual, and is strongly bowed on its outer line. The epiphysis is very narrow with the usual glenoid cavity (Plate 2, figs. 19, 21, and 20, area IV). Duncan (1889a, p. 40) is mistaken in saying of the Echinothuriidae that epiphyses are wanting; they doubtless exist in all regular Echini

possessing jaws. The brace is of the usual shape, and the compasses are strongly arched, curving over the outer border of the braces (Plate 2, fig. 19). The muscles of *Phormosoma* are of the usual number in lanterns of regular Echini, but in addition extra muscles are given off from the auricles radially. These muscles (text-fig. 226, p. 193) are very delicate and may fairly be called radial peristomal and radial somatic muscles, as they extend like tent-ropes from the auricles radially to these two areas. They have been described in *Asthenosoma* as longitudinal muscles (Lang, 1896, p. 471), but this name seems inappropriate. These muscles apparently cause movements of the highly flexible test of the corona and peristome (p. 195).

The Aulodonta have the primitive structure of grooved teeth and narrow epiphyses seen in the Echinocystoida, Perischoechinoida and Cidaroida. With this they have the deep foramen magnum, prominent styloid processes, and especially pits in the top of the pyramids characteristic of the Centrechinoida.

Stirodonta.—*Salenia* is a type of much interest. Duncan (1889a) gives the characters of the lantern, but I believe they have not been shown in detail or figured. The teeth are keeled and supported by the dental slides and styloid processes as usual (Plate 4, figs. 3, 4). The pyramids are rather wide-angled, have a deep foramen magnum (Plate 4, fig. 3), and when the epiphyses are removed, show pits in their dorsal faces (Plate 4, fig. 4, area I). The epiphyses are very narrow, only slightly more than covering the dorsal faces of the half-pyramids (Plate 4, fig. 4, area I). The foramen magnum is therefore open dorsally. The braces and compasses have the usual shape. The protractor and radial compass muscles pass from their origin in the half-pyramids and compasses to the basicoronal plates of the half-interambulacra associated with the area in which they originate (Plate 4, figs. 4, 5). The retractor muscles pass from the half-pyramids to auricles developed from the ambulacra. In *Salenia* the keeled teeth, deep foramen magnum, pits in the dorsal face of the pyramids, and the auricles are all characters which unquestionably locate this type as one of the Centrechinoida and equally separate it from the Cidaroida with which group *Salenia* was formerly associated (p. 195).

The lantern of *Stomopneustes variolaris*, I believe, has not been described. It is erect, with teeth keeled, epiphyses narrow, not meeting in suture over the foramen magnum (Plate 4, figs. 8-10). The dorsal ends of the half-pyramids extend inward over the foramen and at their free ends are produced ventrally as spurs which meet and give support to the teeth. The function of these pyramidal spurs is similar to that of the crests developed on the epiphyses of the Camarodonta (text-fig. 213), but they cannot be homologized with them as they arise from a different structural part. I believe this is a feature which has not hitherto been noted in the lantern of Echini. *Stomopneustes* has been placed in the Echinometridae, but the structure of the lantern would locate it in this suborder, and it seems that it may be safely followed as a basis of classification. In *Glyptocidaris* (*Phymosoma*) *crenulare*, the only living representative of its family, the Phymosomatidae, the structure of the lantern is as in Stom-

opneustes, teeth keeled, foramen magnum open, epiphyses narrow, and spurs from the produced dorsal tips of the pyramids supporting the teeth. These characters link these two families together and equally separate them from other families of regular Echini.

In *Arbacia*, as in *Salenia*, the teeth are keeled (text-fig. 212). The pyramids have a rather deep foramen magnum, and the upper faces of the half-pyramids, seen when the epiphyses are removed, show a pitted surface. The epiphyses are narrow, little more than capping the half-pyramids, so that the foramen magnum is open dorsally. The braces of *Arbacia* are of the usual type, but the compasses are distally rounded instead of bifid as in most Echini. This feature was found in *Arbacia lixula*, *A. punctulata*, and *A. nigra*, so that it is probably generic.

The Stirodonta as regards the lantern present features intermediate in character, having narrow epiphyses as in the Aulodonta and still more primitive types, but keeled teeth like the Camarodonta. Keeled teeth are evidently mechanically more powerful than grooved teeth (text-figs. 207-212, p. 184). Therefore this structure can be considered a mechanical as well as a structural advance over what obtains in the lower groups of Echini.

Camarodonta.—*Tripneustes* represents the most complex structure known in the Centrechinoida. The teeth are keeled (text-fig. 213), and are supported by the dental slides. The epiphyses are wide and meet in a median suture over the foramen magnum. In addition, the epiphyses bear crests, which are strongly developed in *Tripneustes*, and these processes bear against and give support to the teeth at their upper portion. The pyramids are nearly perpendicular and have a deep foramen magnum, which is roofed over by the joined epiphyses. The dorsal face of the half-pyramids, seen when the epiphyses are removed, shows the pits characteristic of the order. The styloid processes are strongly developed, as seen in face view. The epiphyses have the usual glenoid cavity and tubercles for articulation with the brace. The brace is of the usual character, and the ossicles of the compass are divided into two parts and are distally cleft as usual. *Strongylocentrotus* as previously described (Plate 5) is essentially like *Tripneustes*. A peculiar variation was found in a specimen of *Tripneustes esculentus* from Bermuda. In this there are no pits in the top of the pyramids, and as such it may be considered a regressive variant. It is the only case seen in the Centrechinoida in which these characteristic pits are wanting.

The character of the Camarodonta as described is to have keeled teeth and wide epiphyses meeting in suture over the foramen magnum; also the epiphyses bear crests which give support to the teeth. This is the feature of the Temnopleuridae as ascertained in *Temnopleurus*, *Microcyphus*, and *Amblypneustes*. It is the character of the Echinidae as ascertained in *Echinus*, *Toxopneustes*, and *Tripneustes*, and of the Strongylocentrotidae, as seen in *Sphaerechinus* and *Strongylocentrotus*. Finally, it is the character of the Echinometridae, as ascertained in *Echinometra* and shown by Mr. Agassiz (1908) in *Colobocentrotus*. The lantern of the Camarodonta is mechanically as well as structurally the most highly evolved known in Echini.

The keeled teeth as in the Stirodonta are a mechanical advance over grooved teeth (text-figs. 207-213, p. 184). In addition the confluence of the epiphyses (text-fig. 213, p. 184; Plate 5, figs. 2, 5, 9) is a mechanical advance, as, besides supporting the teeth, it makes with the braees a continuous rigid base as fulera for the action of the interpyramidal museles, instead of a distinct continuous base as occurs in all lower Eehini (text-figs. 207-212, p. 184; Plate 2, figs. 19, 20; Plate 27, figs. 5, 6).

Turning to the irregular Eehini, Lovén (1892) and Hawkins (1909) showed that in Discoidea, representing the Holeetypina, the pyramids are wide-angled. This is like the character in the young of Recent regular Eehini and in the adult of Palaeozoic species, so that in Discoidea it may be considered a regressive type of lantern (p. 218). Lovén (1892) worked out the lantern and museles of several of the Clypeastrina with minute care. The lantern in this suborder is highly flattened, broadened, and specialized in character, being very different from the same structure in any regular Eehini. A representative portion of a lantern of Clypeaster is shown in text-figs. 214-216 for comparison. The tooth is short and narrow, and the keel, which is relatively very wide (text-fig. 215), makes up a large part of the mass of the tooth. A little depression in the tip of the tooth, represented in section, is probably due to mechanical wear. The keeled teeth of the Clypeastrina indicate a relation of this group to regular Eehini with keeled teeth. When the lantern is held in its natural plane (text-fig. 214), only the dorsal tip of the tooth is visible, but if rotated upward (text-fig. 216), the ventral tip is seen as well. The pyramids are broadly triangular and procumbent with a lateral expansion into great wings which are deeply plicate on their outer faces. The median suture exists as usual; the foramen magnum is extremely shallow, almost a straight line. On the lateral wings of the half-pyramids there are no corrugations, as in regular Eehini, for the attachment of interpyramidal museles, although these are well developed. On the dorsal face of the half-pyramid seen when the epiphysis is removed (text-fig. 214B), there are no pits as in the Centreechinoida, but the surface is smooth. The epiphyses are very small and the braee is a small, narrow, block-shaped plate quite different from that of the regular Eehini. The compasses are wanting, apparently an ordinal character.

The Aristotle's lantern is an internal structure and as such is not so likely to be affected by external conditions as the more superficial parts of an urchin. It seems, therefore, that its structure as a complicated mechanism should yield data of classificatory value, binding together the larger groups, and I believe that the facts fully support this view.

Summing up the characters briefly: in the Palaeozoic Echinoeystoida and Perischoechinoida (text-figs. 207, 208), the lantern is inclined at an angle of about 45 degrees, not erect. The teeth are grooved, pyramids wide-angled, foramen magnum moderately deep, epiphyses narrow, and there are no pits in the top of the pyramids.

In the ancient Cidaroida (text-fig. 210) the structure is similar, but the lantern is erect, the foramen magnum very shallow, and there are no pits in the top of the pyramids.

In the Centrechinoida, as an order, there are pits in the top of the pyramids beneath the epiphyses, the foramen magnum is always deep, styloid processes are visible in face view, and the lantern is erect excepting in *Astropyga* and the Echinothuriidae, where it is inclined as in the young, and the adult of Palaeozoic types. Other characters of the lantern in this order are sufficiently distinctive to justify the formation of three suborders, as shown (p. 183). In all the above the lantern is made up of forty pieces, braces and compasses are nearly alike, and corrugations exist on the pyramidal wings for attachment of interpyramidal muscles.

In the Holcotypina the structure of the lantern in Discoidea was shown in part by Lovén (1892), and has recently been shown very completely by Hawkins (1909) in *Discoidea cylindrica*. As Hawkins shows, the teeth are narrow, elongate, and keeled; pyramids are wide-angled with a rather deep foramen magnum and laterally with corrugations for the attachment of interpyramidal muscles; the epiphyses are relatively large but narrow and closely resemble those of the Stirodonta. In the whole structure the lantern approaches much nearer to that of the Stirodonta than of any other group of Echini. Of course it may differ in other genera of the Holcotypina where it is at present unknown (see p. 218).

In the Clypeastrina the lantern is procumbent, but is more erect in the young, as I have seen in *Echinarachnius parma*. The teeth are keeled, the foramen magnum is extremely shallow (text-figs. 214–216), pyramids are highly modified with wing-like extensions without ridges for the attachment of interpyramidal muscles, or pits in the top of the pyramids; brace and epiphyses are very small, and compasses are absent. The whole lantern is much specialized, the keeled teeth presenting the best connecting character (see p. 218).

The Spatangina as a suborder are characterized by the absence of the lantern, and it is of highest interest that a lantern exists in young Echinonëus, as shown by Mr. Agassiz (1909). In a very early stage this type has a lantern with keeled teeth, deep, open foramen magnum and bifid compasses, the retractor muscles are attached to the ambulacral auricles, and the protractor and radial compass muscles are attached to the base of the single primordial inter-ambulacral plates. It is interesting and suggestive that this combination of characters shown by Mr. Agassiz in young Echinonëus finds an exact parallel in adult Arbacia (text-fig. 212, p. 184; text-fig. 227, p. 193), and further, the Stirodonta, as here defined, is the only group of regular Echini that does possess such a combination of characters (p. 217).

Before considering the perignathic girdle and the relation of the lantern muscles to the same, I would call attention to the relation of the lantern and muscles to the test as a whole. In the Centrechinoida, as Lovén (1892, p. 44) said, "the retractors of every pyramid are attached on different ambulacra, each on a rising auricular branch." He considered the muscles arising from a single pyramid, the halves of which are united by suture, whereas I take the two half-pyramids united by the interpyramidal muscles as the basis of consideration. The distinction is purely a morphological one. In other words, a pyramid may be considered as inter-

radial in position, its two halves united by suture and embracing the tooth (text-fig. 210). This is the usual way of considering it, and undoubtedly the best for description of the lantern itself. Or a pyramid may be considered as radial in position, the two halves united by the interpyramidal muscle being the unit, and the halves thus considered are the point of origin of all the lantern muscles that are inserted in one radial coronal element (text-figs. 218, 219). As stated (pp. 43, 62), the corona of a sea-urchin may be considered as made up of five elemental radial parts, each of which is developed in relation to one of the ocular plates, as it is at this point that all new coronal plates originate. Any one of these five parts consists of an ambulacrum and on each side a half-interambulacrum, as these originate on the ventral border of the overlying ocular plate. The genitals are omitted from this consideration as coronal plates do not originate in relation to them and one may be absent (spatangoids) without affecting the corona (p. 167.) This relation is shown in *Palaeochinus* drawn from the exterior (text-fig. 217), and *Eucidaris* drawn from the interior (text-fig. 218). The other half-interambulacra not figured would be associated with the next adjacent ambulacra and ocular plates on either side. The compass, brace, and two half-pyramids face this ideal radial area, as in text-figs. 218-220, but the teeth would be interradian in position. In *Eucidaris* (text-fig. 218) the radial compass muscles, protractors, and retractors pass to the apophyses of the two half-interambulacra on either side. In *Centrocchinus* (text-fig. 219) the radial compass muscles and protractors, as in *Eucidaris*, pass to the apophyses of the two associated half-interambulacra, but the retractors have been transferred to the two auricles that develop on the ambulacrum (compare text-fig. 225). This divides the sea-urchin more naturally than to consider the ambulacrum as one and the interambulacrum as a second and independent part.

The perignathic girdle has been studied by Duncan (1885a) and critically by Lovén (1892). I have little to add to their studies except a correlation with fossils and a general summing up of relations. In text-figs. 221-236 is shown the base of two ambulacral and two interambulacral areas of the corona, seen from within, with one set of those lantern muscles that are inserted on the base of the corona. Thus the structure is shown both with and without the associated muscles in the leading orders and representative families of Echini. Bather (1909) has shown that in the Permian *Miocidaris keyserlingi* there are apophyses (text-fig. 238 bis) as in the Recent cidarids, but in other Palaeozoic genera no perignathic girdle has been found in any type, and all the evidence goes to prove that no such structure existed. I have seen as actual tests or internal molds the interior of the basicoronal plates in *Lepidocentrus*, *Hyattchinus*, *Palaeochinus*, *Lovenechinus* and *Perischodomus*, and in none of these was there a trace of any supports for the attachments of lantern muscles. Moreover, as Lovén (1892) showed in very young *Cidarid*, the muscles are attached directly to the base of the primordial interambulacral plates, no apophyses having at that stage developed. From the structure of the lantern in Palaeozoic genera (Plate 27) it is evident that muscles existed, and it is assumed that the

TEXT-FIGS. 217-220.—Morphology of radii in Echini. The corona consists of five parts, each including an ambulacrum and two half-interambulacra originating beneath an ocular (pp. 35, 43, 62, 86).

217. *Palaeochinus quadriserialis* Wright. Lower Carboniferous. Adapted from Plate 30, fig. 3. $\times 2.5$. Seen from the exterior.

218. *Eucidaris tribuloides* (Lamarek). Bahamas. R. T. J. Coll., 754. $\times 2.7$. Seen from the interior with that portion of the lantern and muscles associated with this coronal element (compare text-figs. 210, 222).

219. *Centrocchinus setosus* (Leske). Florida. R. T. J. Coll., 790. $\times 1.9$. Base of a coronal element and that portion of the lantern and muscles that are associated with this element (compare text-figs. 211, p. 184; 225, p. 193).

220. The same. Face view of the two radial half-pyramids, etc., that are associated with one coronal element. Lettering: *ip.*, interpyramidal muscles; *r. p.*, right half of pyramid 2, and *l. p.*, left half of pyramid 3.

Letters of text-figs. 218-220 as in text-figs. 221-230 (p. 193).

protractor, retractor, and radial compass muscles were attached directly to the base of the interambulacral plates, as restored diagrammatically in *Lovenechinus* (text-fig. 221). This is almost exactly the condition of young *Cidaris*, and is virtually like that of *Arbacia* (text-fig. 227), as far as protractor and compass muscles are concerned. Muscles are not attached to ambulacral areas in any known sea-urchin unless special processes, the auricles, are there existent as in *Centrechinoida*.

Such being the structure of the skeleton and probable position of muscles in the *Perischoechinoida*, the next step in advance is seen in the *Cidaridae* (text-fig. 222). As Lovén (1892) showed in this group, there is a direct vertical growth of the edges of the interambulacral plates on the peristomal border. These growths produce wing-like expansions to which all the perignathic muscles are attached. This arrangement is known only in the *Cidaroida*. As these processes are a direct outgrowth of the interambulacral plates, they may properly be called apophyses. They are very distinct from the separate pieces occurring on the ambulacral areas of the *Centrechinoida*, and these may well retain the name of auricles, previously applied to both. Lovén (1892, p. 38) recognized clearly the morphological distinction of apophyses and auricles, but did not give any distinguishing name to differentiate them. In *Eucidaris* (text-fig. 222) the radial compass muscles, protractors, and retractors are attached to the two apophyses. The ambulacra are quite free of muscles and the character of the apophyses freed

TEXT-FIGS. 221-230.—Base of corona with attachment of lantern muscles in representative regular Echini.

221. *Lovenechinus missouriensis* (Jackson). Lower Carboniferous, Missouri. $\times 2.2$. No perignathic girdle, muscles restored schematically.

222. *Eucidaris tribuloides* (Lamarck). Bahamas. R. T. J. Coll., 742. $\times 3$. All muscles inserted on high apophyses.

223. *Phyllacanthus baculosa* (Lamarck). Mauritius. R. T. J. Coll., 753. $\times 2.2$. Apophyses arched over the ambulacrum, a rare aberrant variant (compare text-fig. 229).

224. The same. R. T. J. Coll., 900. $\times 6.5$. Vertical growths on the proximal side of ambulacral plates; further dorsally these growths exist as fine separate spines extending into the body cavity (compare Plate 3, fig. 12).

225. *Centrechinus setosus* (Leske). Bermuda. R. T. J. Coll., 691. $\times 2.3$. Apophyses high, auricles high, centrally confluent. In this and succeeding figures protractor and radial compass muscles are inserted on more or less developed apophyses, but the retractors are inserted on auricles (compare text-figs. 211, 219, 220).

226. *Phormosoma placenta* Wyville Thomson. Off Cape Sable to Cape May, 956 fathoms. R. T. J. Coll., 778. $\times 2.2$. The apophysis is single, not double, as the single primordial interambulacral plate is retained; auricles have secondary sutures (*s*). Radial peristomal (*per.*) and somatic (*so.*) muscles extend from the auricles to the peristome and corona (compare text-fig. 43, p. 80).

227. *Arbacia lixula* (Linné). Naples Station. R. T. J. Coll., 886. $\times 2.2$. Apophysis very reduced and consists of a single piece as the primordial interambulacral plate is retained. Auricles are separate slender styles.

228. *Arbacia nigra* (Molina). Chili. R. T. J. Coll., 797. $\times 2.2$. Auricles meet in an arch (p. 116).

229. *Strongylocentrotus dröbachiensis* (O. F. Müller). Eastport, Maine. $\times 2.2$. Apophyses low, auricles meeting in an arch (compare Plate 5, figs. 1-12).

230. *Echinometra lucunter* (Linné). Bahamas. $\times 2.2$. Apophyses high, auricles extravagantly developed in a high spoon-shaped arch.

Lettering: *a, b*, left and right ambulacral columns; *ap.*, apophyses; *au.*, auricles; *pr.*, protractor muscles; *r*, radial compass muscles; *re.*, retractor muscles; *s*, suture of auricle with ambulacral plate.

from muscels is shown in one area. The ambulacral plates ventrally and throughout the area passing dorsally bear very fine delicate spines that lie near the middle of the area and extend into the body cavity (Plate 3, fig. 13). Ventrally near the peristome these spines may combine into continuous ridges, as in *Phyllacanthus* (text-fig. 224). Similar spines occur in some Palaeozoic Echini, as *Hyattechinus* (Plate 24, fig. 6); but I have not seen them in the *Centrechinoida* (p. 61).

The apophyses in the *Cidaroida* in the several species seen are typically as in text-fig. 222, high, broad, and flaring over the ambulacral areas. In one area of a specimen of *Phyllacanthus baculosa* (text-fig. 223) the apophyses meet in a suture over the ambulacral area, and Duncan (1885a) shows a similar case in *Phyllacanthus imperialis* (Lamarck). In these aberrant variants the retractor muscles come to occupy a position over the ambulacrum just as they do in *Centrechinus* (text-fig. 225), but with the radical difference that in *Centrechinus* they are inserted on auricles, not on apophyses.

In the *Centrechinoida* a different condition exists in the perignathic girdle. Apophyses may develop on the interambulacral plates to a considerable extent (*Centrechinus*, text-fig. 225; *Echinometra*, text-fig. 230), or apophyses may be much reduced (*Strongylocentrotus*, text-fig. 229; *Arbacia*, text-fig. 227). On the other hand a new character exists not seen in the *Perischoechinoida* nor the *Cidaroida*. This feature is auricles, which, as shown by Lovén (1892), are two pillars, or flattened plates arising from the base of the ambulacra, but separated from the ambulacral plates by sutures. They are not a continuation of the ambulacral plates as apophyses are of the interambulacral plates. Auricles originate on either side of the ambulacrum with an open space between; they may exist as perpendicular isolated pillars (*Arbacia lixula*, text-fig. 227; *Salenia*, Plate 4, fig. 5), or they may arch over the ambulacrum, joining in suture (*Arbacia nigra*, text-fig. 228; *Strongylocentrotus*, text-fig. 229). The joining is a feature of development, as they are apparently always separate in the young. It is also a species differential and subject to individual variation, as well as to radial variation within the individual. Auricles may form high and wide arching plates (*Centrechinus*, text-fig. 225; *Echinometra*, text-fig. 230). When apophyses are developed, the auricles present a suture line at their point of mutual contact (*Centrechinus*, text-fig. 225). The auricles in this order are the points of insertion of the retractor muscles of the lantern, which are thus located instead of being inserted on the apophyses as in the *Cidaroida*, a marked ordinal distinction. The protractor and radial compass muscles, however, are inserted on the apophyses, as in the *Cidaroida*.

Taking up the representative types shown, in *Centrechinus* (text-fig. 225) the apophyses are high and auricles very high, broad, and meeting in an arch over the ambulacra. The protractor muscles are powerful and with the radial compass muscles are attached to the apophyses. The retractors are also powerful and are inserted high up on the arch of the auricles.

In *Phormosoma* (text-fig. 226) the primordial interambulacral plate is retained in the adult in the basicoronal row (text-fig. 43, p. 80), so that the apophysis consists of the upward growth of one plate, instead of two plates as in *Centrechinus*; therefore there is no median suture. The apophysis is low and bears the radial compass and rather slender protractor muscles. The auricles are exceptional in that each consists of two pieces joined by suture instead of one piece, as in all other families of the order. The retractor muscles are inserted on the upper of these two pieces. Another striking character of the auricles is that muscles extend from them radially in two directions. The radial peristomal muscles extend inward, and the radial somatic muscles outward, being inserted on the plates of the peristome and corona respectively. Such muscles have been described in *Asthenosoma* (Lovén, 1892, p. 45). Bell (1889, p. 438) says that these radial or "Langsmuskeln" are altogether wanting in *Phormosoma*, but he is quite mistaken.

In *Salenia* (Plate 4, figs. 4, 5) the apophyses are low and on them are inserted the protractor and radial compass muscles. The auricles are slender, not meeting in an arch, and bear the retractor muscles. This structure as well as the lantern of *Salenia* is entirely characteristic of its order, not showing any features of the *Cidaridae* with which the *Saleniidae* were formerly associated (p. 186).

In *Arbacia lixula* (text-fig. 227) the primordial interambulacral plate exists in the basicoronal row, and the apophysis of this single plate is so slight that it can hardly be considered more than a thickening of the same. To it the protractor and radial compass muscles are attached, as usual. The auricles are simple isolated columns standing quite free and bearing the retractor muscles. In *Arbacia nigra* (text-fig. 228) the auricles may join in an arch over the ambulacrum, though frequently they do not join, and there is considerable diversity in this character in different specimens or in different areas of the same specimen. This joining of the auricles in an arch is a progressive character and *A. nigra* has other progressive features, as previously discussed (p. 116), marking it as a specialized species in its genus.

Strongylocentrotus dröbachiensis (text-fig. 229) has low but well marked apophyses, to which are attached the protractor and radial compass muscles. The auricles are arched, meet in a median suture, and bear the retractor muscles. In young specimens the auricles are separate. As a matter of individual variation, in adults occasionally the auricles do not join in an arch, but retain the youthful and more primitive character of separate pillars.

In *Echinometra lucunter* (text-fig. 230) the perignathic girdle is a very striking structure. The apophyses are high, strongly developed, and bear powerful protractor and compass muscles. The auricles are thick, solid, extraordinarily high, and meet as spoon-shaped plates, arching above the ambulacrum, with a long median suture. The retractor muscles are situated high up on the auricles and are very powerful.

Lovén (1892) gives the characters of the perignathic girdle in *Discoidea* and *Galerites*

representing the Holoetypina, but I have had no opportunity to study them. In these genera low apophyses and auricles exist, and this structure with others affiliates the Holoetypina with the Centrechinoida (p. 218).

In the Clypeastrina the perignathic girdle was described by Lovén (1892) in representative types. It presents striking ordinal characters. Apophyses are wanting, but auricles are developed, and on these are inserted both the retractor and the protractor muscles, whereas in regular Echini the protractors are always attached to the apophyses, or directly on the basicoronal interambulacral plates. As compasses are absent in the Clypeastrina, their muscles, of course, are also absent.

In *Clypeaster subdepressus* (text-figs. 231, 232) the ambulacral plates of the basicoronal row roof over the primordial interambulacral plates so as nearly to cover them, but the interambulacral plates as far as visible are shaded, as seen in areas 2 and 3. The auricles are erect pillars situated on either side of the ambulacrum, and, as the ambulacra arch over the interambulacra, therefore the auricles of two separate ambulacral areas come in juxtaposition, a character seen only in this order. The four retractor muscles of each area are situated on the inner and lateral upper faces of the auricles, and the two protractors, which are very small, are situated on the bases of the same (text-fig. 231). Four retractors are not seen in all clypeastroids, and in other orders there are only two such muscles in each area.

The degree to which the ambulacral plates roof over the primordial interambulacrals in the basicoronal row varies in specimens and in different areas of the same individual. In *Clypeaster rosaceus* (text-figs. 233-235) the beveling is considerable, but the whole length of the interambulacral plate is seen from within, whereas in *Clypeaster subdepressus* (text-figs. 231, 232) the same plate is visible only at intervals. In this beveling of ambulacral plates it is to be distinctly understood that we are considering the interior of the test. As viewed from the exterior, it is a case of the interambulacra beveling over the ambulacrum, as discussed (p. 73).

In *Echinarachnius parma* (text-fig. 236), as shown by Lovén (1892, p. 67), a very remarkable condition obtains; the auricles occur on the primordial interambulacral plates instead of on the ambulacrals, and the small retractor and protractor muscles are inserted on the auricles. In this type, therefore, the retractor and protractor muscles occupy the same interradiar position that they do in the Cidaroida, but instead of being inserted on apophyses, as in that group, they are inserted on transposed auricles, a distinct morphological part.

The case stated in brief is as follows: in the Echinocystoida and Perischoechinoida, as far as known, no perignathic girdle existed, and the muscles were doubtless attached directly on the base of the interambulacral plates. In the Cidaroida, apophyses are developed as upward growths of the basicoronal interambulacral plates, and on these apophyses are inserted protractor, radial compass, and retractor muscles. In the Centrechinoida, apophyses are well or feebly developed, and to them protractors and radial compass muscles are attached, but in this

TEXT-FIGS. 231-236.— Base of corona with attachment of lantern muscles in the Clypeastrina.

231. *Clypeaster subdepressus* (Gray). West Indies. R. T. J. Coll., 887. $\times 2.8$. Ambulacral plates nearly roof over the primordial interambulacral plates. Auricles are high, bearing the insertion of the protractor and two pairs of retractor muscles.

232. The same. $\times 4.7$. Showing the relation of primordial ambulacral and interambulacral plates, the latter shaded.

233. *Clypeaster rosaceus* (Linné). Bahamas. R. T. J. Coll., 888. $\times 5.7$. The primordial interambulacral plate is less completely covered by the ambulacrales than in text-fig. 232.

234. The same. Plates separated, inner view (p. 74).

235. The same. Plates separated, viewed from peristome.

236. *Echinarachnius parma* (Lamarek). Eastport, Maine. $\times$ about 5.7. Auricles are transferred to the primordial interambulacral plate and bear the insertion of protractor and one pair of retractor muscles.

Lettering as in text-figs. 221-230, p. 193.

order a new part appears, auricles, which arise from the ambulacra as separate pieces, and to them the retractor muscles are attached. In the Holcetyrina apophyses and auricles are both existent. In the Clypeastrina, apophyses are wanting, but auricles are developed, and to them protractor and retractor muscles are attached (radial compass muscles are wanting). Further, the auricles in this suborder may arise from the ambulacra, as in the Centrechinoida, or may, as Lovén showed, be transferred to the interambulacral plates occupying an interradian instead of a radial position. In the Spatangina in adults the perignathic girdle is wanting as the lantern is absent. In the young of *Echinoneus*, however, as shown by Mr. Agassiz (1909) and Westergren (1911) auricles are developed on the ambulacra as separate styles, similar to those in the Centrechinoida, as in *Arbacia* (text-fig. 227). Mr. Agassiz (1883, p. 50) has shown that there are small knobs on the interior of the test in the spatangoid *Conolampas sigsbei* A. Agassiz. These knobs are on the base of the ambulacra and appear to be remnants of auricles which typically occupy this position. Not uncommonly in the Spatangina a process with a suture at its base arises from the interior of an ambulacral plate near the peristomal border. Such processes may be considered cases in which an auricle is retained as a reversionary variation.

It is seen that the perignathic girdle presents characters that differ very definitely in the several larger groups of Echini, so that this structure as well as the Aristotle's lantern yields characters of high interest and importance in the comparative morphology and systematic classification of the Echinoidea.

PART II.

SYSTEMATIC CLASSIFICATION OF ECHINI.

As urged by Hyatt, a natural classification of organisms should be based on a comparative study of the young and adult, fossil and living forms; the young because through stages in development they throw light on ancestry; the adult because such are the full expression of generic and specific characters; the fossil because as an essential part of a group they cannot be ignored, and also because to the past one must look for the ancestors of the living. The living representatives as an essential part of a group need consideration, and if one's work is largely palaeontological, a study of the living is of first importance, as the study of soft parts throws great light on the structure of hard parts, as I showed (1890) in studies of Pelecypoda. Variation is only second to development as a basis for studying genetic relations, as variants, both arrested and progressive, have a direct relation to the characters of more primitive or more specialized species or genera in a systematic series.

Echini are classified almost entirely on the structure of skeletal parts, so that well preserved fossils can be studied with almost as much accuracy as living forms. Mortensen has urged the importance of pedicellariae and also spicules in the tube-feet as a basis of classification. I believe no one has shown that these structures have a differential value in ontogeny or in evolutionary series. Moreover, they are minute and difficult structures to ascertain. If one attempts to follow Mortensen's splitting of genera on these characters, it seems that it is necessary to be a specialist on these particular parts in order to perceive the fine distinctions that he draws. Every part of an organism is surely worthy of careful study; but to base classification on such minutiae of no known evolutionary value is undesirable.

The classification here offered conforms for the most part with what I gave in 1896, differing from it only in minor details and going further in certain groups. It is based essentially on the structure of the adult and the development of the same. While no single character has been followed, the characters taken into consideration are: the ambulacrum, interambulacrum, coronal imbrication, basicoronal plates, ventral resorption of corona, ocular and genital plates, periproct, peristome, Aristotle's lantern, perignathic girdle, spines and tubercles, gills and sphaeridia. The relative value of these parts naturally differs in different groups of the Echini. Of Palaeozoic Echini all the genera, except those imperfectly known, are here briefly considered, but of post-Palaeozoic forms only the larger groups are taken into account.

It may be said with truth that all Echini belong distinctly to this class and make no close

approach to other classes of the Echinodermata. Attempts have been made to connect the Echini with the Asteroidea, especially through the genus *Palaeodiscus*, as later discussed, but the present evidence is opposed to this view. Mr. A. H. Clark (1909) has recently attempted to connect the Echini with the Crinoidea. In Echini all plates of the corona originate beneath a permanent plate, the ocular, as they do not in crinoids. The reproductive bodies of Echini are internal and interradial in position, whereas in crinoids they are situated on the arms. The peristome of Echini (excepting the *Exocycloida*) bears ten or more ambulacral plates, as the oral region of crinoids does not. Clark has attempted to correlate the auricles of Echini with ambulacral plates of crinoids. Auricles are unknown in Palaeozoic Echini and the *Cidaroida*; they exist only in the *Centrechinoida* and some *Exocycloida*, both specialized types. Moreover, they do not occur (*Centrechinoida*) at the ventral end of the ambulacra as Clark's theory calls for, but very far from the ventral termination of the ambulacra, which is the row of primordial ambulacral plates around the mouth. This is best seen in *Phormosoma* (text-fig. 226, p. 193), or other echinothuriids, where many rows of ambulacral plates exist between the auricles and the mouth. What the ancestor of the Echini as a class was is unknown, but it might fairly be sought amongst the *Cystoidea*.

The Echini, though possessing a wide range of structure, may be described as animals possessing alimentary, reproductive, nerve, and water vascular systems within an enclosing superficial pentamerous skeleton which bears movable spines. There are from two to twenty columns of plates in each of the five ambulacral areas and from one to fourteen columns of plates in each interambulacral area. New coronal plates are formed at the ventral border of the five ocular plates, ambulacral pores pass through ambulacral plates, rarely (clypeastroids) in part between plates. The peristome in all but the *Exocycloida* bears from one to many rows of ambulacral plates, with or without non-ambulacral plates. There are five oculars (apparently in part or wholly wanting in some of the *Pourtalesiidae*), and five genitals or fewer, the whole being fused into a mass in certain types of *Exocycloida*. The genitals typically have each one or more pores as exits of the five interradially situated reproductive glands. In addition, typically, madreporic pores exist in genital 2, but are not recognizable in most Palaeozoic forms. The periproct is more or less plated, situated within the oculo-genital ring, or in irregular types outside of that area; the anus is in the periproct. The masticatory lantern is composed of forty pieces (or clypeastroids thirty pieces); it is wanting in adult spatangoids. Respiratory organs consist of Stewart's organs, peristomal or ambulacral gills. Locomotion is effected by ambulacral feet or by spines, or both.

Such being the character of the class as a whole, the following key presents the characters by which the several groups may be divided. It is too much to hope that errors of diagnosis will have been entirely overcome, but it is felt that it is an approximation to the real affinities as gathered from a comparative study of the characters of young, adult, fossil, and living types.

In Palaeozoic types the given characters, especially of the peristome, may be known in only one or a few cases, and further study may require modification in details. A genealogical table is given (p. 209) that presents in a tree form the relations as understood, and following this, as briefly as possible, a consideration of each of the several divisions, the fullest detail being given of the Palaeozoic forms. Post-Palaeozoic genera of the regular Echini, and the families of the Exocycloida are not included.

Key to the Classification of the Echinoidea.

- I. Two columns of high hexagonal plates in each ambulacral area, and one column of plates in each interambulacral area. Order BOTHRIOCIDAROIDA.

With characters of the order. Family BOTHRIOCIDARIDAE.

Ambulacral pores superposed in the center of plates. Plates not imbricate. Primordial ambulacral plates around mouth in the peristome. Primordial interambulacral plates in basicoronal row. Base of corona not resorbed. Oculars very large, genitals very small. Periproct with many small plates. Peristome with two rows of ambulacral plates only. Jaws.

Bothriocidaris (three species).

- II. Two or more columns of plates in each ambulacral area, and two or more columns of plates in each interambulacral area.

A. Two columns of simple or compound plates in each ambulacral area, and two columns of plates in each interambulacral area (for AA, see p. 205).

B. Periproct within oculo-genital ring (for BB, see p. 204).

C. Ambulacral plates low, simple; two (in one genus, *Tetraecidaris*, partly four) columns of plates in each interambulacral area. Coronal plates rarely imbricate (*Miocidaris*). Primordial ambulacral plates around the mouth in the peristome. Primordial interambulacral plates resorbed. Base of corona resorbed. Oculars all exsert, or becoming insert in the sequence V, I, IV, II, III, or V, I, IV, III, II. Periproct covered with many thick plates. Peristome with many rows of ambulacral and interradial non-ambulacral plates, or rarely ambulacral plates only. Lantern erect, teeth grooved, foramen magnum very shallow; epiphyses narrow. No pits in the top of pyramids. Pyramids with ridges on lateral wings. Perignathic girdle consisting of apophyses only. Stewart's organs present. Primary spines with a cortical layer. Primary tubercles perforate. Sphaeridia absent.

Order CIDAROIDA.

With characters of the order. (Only one assured genus of this family occurs in the Palaeozoic, therefore other genera are omitted.) Family CIDARIDAE.

Interambulacral plates beveling over the ambulacral on the adradial suture. (Two species only of this order and genus are definitely known in the Palaeozoic.)

Miocidaris.

- CC. Ambulacral plates compound, rarely simple; two columns of plates in each interambulacral area. Coronal plates not imbricate or imbricate. Primordial ambulacral plates around the

mouth in the peristome. Primordial interambulacral plates in the basicoronal row, or usually resorbed. Base of corona not resorbed, or usually resorbed. Oculars all exsert or becoming insert in the sequence I, V, or V, I, IV, II, III. Periproct plated with few or many plates, or granules, or largely leathery. Peristome with ten primordial ambulacral, also non-ambulacral plates, or in one family many rows of ambulacral plates only. Lantern erect or rarely inclined; teeth grooved, or keeled; foramen magnum deep; epiphyses narrow, or else wide and uniting in suture over the foramen magnum. Pits in the top of pyramids. Pyramids with ridges on lateral wings. Perignathic girdle consisting of low or high apophyses, and auricles. Peristomal gills, rarely with Stewart's organs in addition. Primary spines without a cortical layer. Primary tubercles perforate or imperforate. Sphaeridia present.

Order CENTRECHINOIDA.

D. Teeth grooved. Epiphyses narrow, not meeting in suture over the foramen magnum. Ambulacral plates simple or compound. Coronal plates imbricate or not. Primordial interambulacral plates resorbed or retained in the basicoronal row. Base of corona resorbed or not. Oculars all exsert, or becoming insert in the sequence I, V, IV, II, III. Periproct with many plates or granules, or largely leathery. Lantern erect or inclined. Primary tubercles usually perforate. Suborder *AULODONTA*.

Ambulacral plates compound ventrally, simple above the mid-zone, or in some genera compound throughout. Coronal plates thick, not imbricating. Base of corona resorbed. Oculars all exsert, or one, or two may be insert. Periproct unknown. Peristome unknown. Lantern erect. Family *HEMICIDARIDAE*.

Ambulacral plates simple. Coronal plates thin, not imbricating. Base of corona resorbed. Oculars large, insert. Periproct leathery, but partially plated. Peristome with ten very large primordial ambulacral plates. Lantern erect.

Family *ASPIDODIADEMATIDAE*.

Ambulacral plates compound. Coronal plates not imbricate (Mesozoic), or more or less imbricate (Recent). Base of corona resorbed. Oculars exsert, or one to all insert. Periproct more or less plated, to nearly leathery. Peristome with ten primordial ambulacral, also non-ambulacral plates. Lantern erect, or (*Astropyga*) inclined. Stewart's organs slight, or absent. Family *CENTRECHINIDAE*.

Ambulacral plates compound. Coronal plates very thin, imbricate. Primordial interambulacral plates in basicoronal row. Base of corona not resorbed. Oculars insert, often separated from the genitals by interspaces. Genitals more or less split by secondary sutures. Periproct leathery but partially plated. Peristome with many rows of ambulacral plates only. Lantern inclined. Radial peristomal and somatic muscles. Stewart's organs. Family *ECHINOTHURIIDAE*.

DD. Teeth keeled.

E. Epiphyses narrow, not meeting in suture over the foramen magnum. Ambulacral plates compound or largely simple. Coronal plates not imbricate. Primordial interambulacral plates resorbed or retained in the basicoronal row. Base of corona resorbed or not. Oculars all exsert or becoming insert in the sequence I, V or V, I, IV, II, III. Periproct with prominent suranal, or with many small plates, or

four, or five large plates only. Peristome with ten primordial ambulacral, also non-ambulacral plates. Lantern erect. Primary tubercles imperforate, or exceptionally perforate. Suborder *STIRODONTA*.

Ambulacral plates compound, or largely simple. Primordial interambulacral plates resorbed. Base of corona resorbed. Oculars exsert or becoming insert in the sequence I, V, IV, II, III. Periproct with a permanent large suranal, or more large plates, with small anal plates. Primary tubercles imperforate, or perforate. No spurs from pyramids supporting teeth.

Family *SALENIIDAE*.

Ambulacral plates compound. Primordial interambulacral plates resorbed. Base of corona resorbed. Oculars becoming insert in the sequence I, V, IV, II, III. Periproct with numerous small plates only. Primary tubercles imperforate. Spurs from pyramids support the teeth dorsally. Family *PHYMOSOMATIDAE*.

Ambulacral plates compound, composed of three elements each, at the mid-zone every four or five ambulacral plates are bound together and grown over by one primary tubercle. Primordial interambulacral plates resorbed. Base of corona resorbed. Oculars becoming insert in the sequence I, V, IV. Periproct with many small plates only. Primary tubercles imperforate. Spurs from pyramids support the teeth dorsally. Family *STOMORNEUSTIDAE*.

Ambulacral plates compound. Primordial interambulacral plates in the basiconal row. Base of corona not resorbed. Oculars all exsert or becoming insert in the sequence V, I, IV. Periproct with four or five large plates only. Primary tubercles imperforate. No spurs from pyramids supporting teeth.

Family *ARNACHIDAE*.

EE. Epiphyses wide, meeting in suture over the foramen magnum. Ambulacral plates compound. Coronal plates not imbricate. Ambitus circular, or elliptical through a sidewise axis. Primordial interambulacral plates resorbed. Base of corona resorbed. Oculars all exsert or becoming insert in the sequence V, I or I, V, IV, II, III. Periproct usually plated with many small plates (in one genus, *Parasalenia*, with four large plates). Peristome with ten (in one species five) primordial ambulacral plates and more or fewer non-ambulacral plates; rarely the latter are absent. Lantern erect. Primary tubercles imperforate.

Suborder *CAMARODONTA*.

Ambitus circular. Pits, or sculpturing in coronal plates dorsally. Ambulacral plates at mid-zone composed of three elements each. Oculars usually all exsert.

Family *TEMNOLEURIDAE*.

Ambitus circular. No pits or sculpturing in coronal plates dorsally. Ambulacral plates at mid-zone composed of three elements each, rarely dorsally of two elements. Oculars all exsert, or becoming insert in the sequence I, V, IV, II, III. Family *ECHINIDAE*.

Ambitus circular. No pits or sculpturing in the coronal plates. Ambulacral

plates at mid-zone composed of from four to ten elements each, rarely (some *Echinostrephus*) of three elements each. Oculars all exsert or becoming insert in the sequence I, V, IV, II. . . . Family *STRONGYLOCENTROTIDAE*.

Ambitus elliptical in a sidewise axis. No pits or sculpturing in coronal plates dorsally. Ambulacral plates at mid-zone composed of four or more elements each, rarely (*Parasalenia*) of three elements each. Oculars all exsert, or becoming insert in the sequence V, I, IV. . . . Family *ECHINOMETRIDAE*.

- BB. Periproct outside of oculo-genital ring, in interambulacrum 5. Regular in form, or more frequently more or less markedly bilaterally symmetrical through the axis III, 5. Slight or no resorption of base of corona by the advance of the peristome. Lantern present or absent. Peristomal gills, or ambulacral gills only. Sphaeridia present. . . . Order *EXOCYCLOIDA*.

Ambulacral plates compound, or largely simple, areas not petaloid dorsally. Primordial ambulacral plates unknown. Primordial interambulacral plates in basicoronal row, or in part resorbed. Base of corona slightly resorbed. Oculars and genitals all present and distinct, or fused, or genital 5 absent; when present, it is imperforate. Periproct unknown. Peristome central, structure unknown. Lantern inclined so far as known. Teeth keeled, epiphyses narrow. Foramen magnum moderately deep. Pyramids with ridges on lateral wings. Perignathic girdle consisting of low apophyses and auricles. Peristomal gills present. . . . Suborder *HOLECTYPINA*.

Ambulacral plates simple, areas petaloid dorsally. Ventrally ambulacral pores are minute and specialized. Primordial ambulacral plates in basicoronal row. Primordial interambulacral plates in basicoronal row, or exceptionally (*Arachnoides*, p. 72) pushed dorsally and in part resorbed by intraeoronal resorption. Base of corona not resorbed. Ocular and genital plates fused in a mass, usually no genital pore in area 5. Genital pores within the fused mass or outside in interambulacra 1, 2, 3, 4. Periproct plated. Peristome central, leathery. Lantern procumbent, highly modified, teeth keeled, foramen magnum very shallow, small epiphyses and braces, but no compasses. Pyramids usually without ridges on lateral wings. Perignathic girdle consisting of auricles only, on ambulacral, or on interambulacral plates. No peristomal, but ambulacral gills only.

Suborder *CLYPEASTRINA*.

Ambulacral plates simple, areas commonly petaloid dorsally; in some types pores are absent in part of the plates. Ambulacrum III often differs markedly in character from other areas. Ambulacral plates often highly specialized in form and size. Primordial ambulacral plates in the basicoronal row, or (*Pourtalesia*) in part pushed dorsally. The basicoronal plates Ia, IIa, IIIb, IVa, Vb are larger and with two pairs of pores or two separate single pores, whereas the Ib, IIb, IIIa, IVb, Va are smaller with one pore-pair or one single pore. Primordial interambulacral plates in basicoronal row or (*Lovenia*, *Pourtalesia*) pushed dorsally. Base of corona not resorbed. Oculars and genitals separate, or genitals partially fused. Oculars apparently absent in some *Pourtalesias*. Genital 5 absent, and some additional genitals rarely absent. Periproct plated. Peristome eccentric, plated with non-ambulacral plates only. Lantern and perignathic girdle absent (present in the young of *Echinoneus*, pp. 189, 217). No peristomal, but ambulacral gills only.

Suborder *SPATANGINA*.

AA. Two or more columns of simple plates in each ambulacral area, and three or more columns of plates in each interambulacral area (for A, see p. 201).

B. Genitals largely covering the dorsal surface. Two columns of low plates in each ambulacral area and three columns of plates in each interambulacral area. Plates not imbricate. Primordial interambulacral plates in basicoronal row. Base of corona not resorbed. Oculars small, strongly exert by the contact of large genitals. Periproct central, structure unknown. Peristome central, structure unknown. Lantern and perignathic girdle unknown.

Order PLESIOCIDAROIDA.

BB. Genitals small. Two to twenty columns of plates in each ambulacral area and three to fourteen columns of plates in each interambulacral area. Plates not imbricating, or imbricating; when the latter, ambulacral plates imbricate ventrally and interambulacral plates dorsally and from the center laterally and over the ambulacra on the adradial sutures. Primordial ambulacral plates on the peristome. Base of corona resorbed or not. Peristome central with many rows of ambulacral plates only, or the same with non-ambulacral plates. Lantern inclined, composed of 40 pieces, teeth grooved. Foramen magnum moderately deep, epiphyses narrow. No pits in top of pyramids. No perignathic girdle. No peristomal gills. Primary spines and perforate tubercles with secondary spines and imperforate tubercles, or secondaries only.

C. Irregular, periproct apparently in an interambulacrum. Two to four columns of plates in an ambulacral area, and eight to nine columns of plates in an interambulacral area. Plates thin, imbricating. Oculars and genitals doubtful. . . . Order ECHINOCYSTOIDA.

Two columns of plates in an ambulacral area and eight to nine columns of plates in an interambulacral area. Primordial interambulacral plates in basicoronal row. Base of corona not resorbed. Peristome with ambulacral plates only. Lantern typically echinoid. Numerous fine spines. (One genus and species.) Family PALAEODISCIDAE.

Four columns of plates in an ambulacral area, and eight columns of plates in an interambulacral area. Small primary spines and tubercles. (One genus and species.)

Family ECHINOCYSTIDAE.

CC. Regular, periproct within oculo-genital ring. Two to twenty columns of plates in each ambulacral area, and three to fourteen columns of plates in each interambulacral area. Plates imbricate or not. Primordial interambulacral plates in basicoronal row, or resorbed. Base of corona not resorbed or resorbed. Oculars usually all insert. Genitals typically with more than one pore each; rarely (*Lepidechinus*) with one pore each. Madreporite usually not recognizable. Periproct covered with many thick plates. Peristome with many rows of ambulacral plates only, or in addition with interradiat non-ambulacral plates. Spines primary and secondary, or the latter only. Primary tubercles perforate, secondary tubercles imperforate. Order PERISCHOECHINOIDA.

D. Two columns of plates in each ambulacral area, four to fourteen columns of plates in each interambulacral area. Plates thin, imbricating.

E. Four to eight columns of plates in an interambulacral area. Primordial and additional interambulacral plates resorbed in the advance of peristome. Oculars, genitals, and periproct imperfectly known. Peristome with many rows of

ambulacral and interradial non-ambulacral plates. Spines large primaries with perforate tubercles in the center of each interambulacral plate, also secondary spines and imperforate tubercles. Family ARCHAEOCIDARIDAE.

Fragmentarily known from dissociated interambulacral plates and spines.

Plates similar to those of *Archaeocidaris* but primary tubercles without a basal terrace. *Eocidaris* (one species).

Ambulacral plates all alike, of equal height. Four columns of plates in an interambulacral area. Primary spines large, tapering, or inflated, smooth, or with lateral spinules. Primary tubercles with basal terrace and scrobicular ring. *Archaeocidaris* (many species).

Ambulacral plates low, with also higher, wider and wedge-shaped plates. Six to eight columns of plates in an interambulacral area. Primary spines cylindrical. Primary tubercles with no basal terrace, but with scrobicular ring.

Lepidocidaris (one species).

EE. Five to fourteen columns of plates in an interambulacral area. Primordial interambulacral plates in basicoronal row. Base of corona not resorbed. Oculars insert. Genitals with many pores each. Peristome with many rows of ambulacral plates only. Spines small eccentrically placed primaries with secondaries, or the latter only. Family LEPIDOCENTRIDAE.

Test high, probably spheroidal; ambulacral plates high, two or three equaling the height of an adambulacral plate, pore-pairs uniserial. Seven to eight columns of nearly rhombic plates in an interambulacral area.

Koninckocidaris (two species).

Test high, spheroidal, ambulacral areas narrow throughout; ambulacral plates low, about eight equaling the height of an adambulacral plate, pore-pairs uniserial. Five to eleven columns of plates in an interambulacral area. Small primary spines and tubercles with secondaries on interambulacral plates.

Lepidocentrus (five species).

Test depressed to flattened; through the ambitus circular, pentagonal, or clypeastriform. Ambulacral areas broad, petaloid ventrally, narrow dorsally, pore-pairs uniserial. Eleven to fourteen columns of plates in an interambulacral area. Small primary and secondary tubercles on interambulacral plates.

Hyattechinus (three species).

Test high, spheroidal, ambulacral areas narrow throughout, pore-pairs moderately biserial. Nine to ten columns of plates in an interambulacral area.

Secondary spines and tubercles only. . . . *Pholidechinus* (one species).

DD. Two to twenty (usually more than two) columns of plates in each ambulacral area, three to eleven columns of plates in each interambulacral area. Plates not imbricate or imbricate.

E. Test elliptical, obovate, spherical or subspheroidal. Two to twelve columns of plates in each ambulacral area, three to eleven columns of plates in each

interambulacral area. Plates not imbricate, but ambulacral plates bevel over the interambulacral on adradial sutures. Primordial interambulacral plates resorbed. One row only of interambulacral plates resorbed in advance of the peristome. Oculars usually all insert, genitals usually with three to five pores each. Peristome with many rows of ambulacral and some interradial non-ambulacral plates (Plate 56, figs. 7, 8). Secondary spines and imperforate tubercles only.

Family PALAEECHINIDAE.

Two columns of plates in each ambulacral area, consisting of plates which are all primaries; pore-pairs uniserial. Four to six columns of plates in each interambulacral area. *Palaeochinus* (four species).

Two columns of plates in each ambulacral area, consisting of plates which are alternately primaries and partially or completely ocluded; pore-pairs biserial. Four to eight, or nine columns of plates in each interambulacral area.

Maccoya (six species).

Four columns of plates in each ambulacral area, consisting of demi- and ocluded plates; pore-pairs biserial. Four to seven columns of plates in each interambulacral area. *Lorenechinus* (six species).

Four columns of plates in each ambulacral area, consisting of demi-, ocluded, and in addition scattered isolated plates; pore-pairs multiserial. Four to nine columns of plates in each interambulacral area. *Oligoporus* (five species).

Six to twelve columns of plates in each ambulacral area, consisting of demi-, ocluded, and one to four irregular columns of isolated plates in each half-area at the mid-zone; pore-pairs multiserial. Three to eleven columns of plates in each interambulacral area. *Melonechinus* (fourteen species).

EE. Test elliptical, obovate, spherical, or subspheroidal. Two to twenty columns of plates in each ambulacral area. Three to thirteen columns of plates in each interambulacral area. Plates imbricate. Primordial interambulacral plates in basiacoronal row. Base of corona not resorbed. Oculars usually all insert, genitals with one to many pores each. Periproct plated with many thick plates. Peristome with many rows of ambulacral plates only. Primary spines with perforate tubercles, usually eccentric and irregularly distributed on interambulacral plates, with secondary spines and tubercles, or the latter only. Family LEPIDESTHIDAE.

Two columns of plates in each ambulacral area. Four to eight columns of plates in each interambulacral area. Plates quite thick, imbricating moderately. Secondary tubercles only. Genital plates as far as known with only one pore each, the only instance known in the Palaeozoic. Resembles *Palaeochinus* excepting for the imbrication. *Lepidechinus* (four species).

Two columns of plates in each ambulacral area. Five columns of plates in each interambulacral area. Plates imbricating strongly. Eccentric perforate primary with secondary tubercles on interambulacral plates. Genital plates with many pores. *Perischodomus* (two species).

Six columns of plates in each ambulacral area. Five columns of plates in each interambulacral area. Plates apparently imbricating moderately. Eccentric primary tubercles on certain adradial plates, with secondary tubercles on the same and alone on other interambulacral plates.

Perischocidaris (one species).

Four columns of plates in each ambulacral area. Eleven to thirteen columns of plates in each interambulacral area. Plates strongly imbricating. Small primary with secondary spines and tubercles on interambulacral plates.

Proterocidaris (one species).

Eight to sixteen columns of plates in each ambulacral area. Three to seven columns of plates in each interambulacral area. Plates strongly imbricating; plates all of uniform size. Secondary spines and tubercles only. Test elliptical, obovate, or spherical. . . . *Lepidesthes* (ten species).

Four to six columns of plates in each ambulacral area. Five to six columns of plates in each interambulacral area. Plates strongly imbricating. Ambulacral plates large ventrally, small dorsally; interambulacral plates dorsally very large in adambulacral columns, smaller within. Eccentric primary spines and tubercles with secondaries on dorsal adambulacral plates, and secondaries only on interambulacral plates of dorsal median columns.

Pholidocidaris (four species).

Twenty columns of plates in each ambulacral area. Three columns of plates in each interambulacral area. Plates of uniform size, imbricating strongly. Small central primary spines and tubercles with secondary spines and tubercles on ambulacral and interambulacral plates. Teeth distally serrate, a unique character. . . . *Meekchinus* (one species).

Having considered the systematic relations of the Echini in the form of a key and in a genealogical table I will give briefly the reasons for the several steps which will be more completely gathered from the morphological studies, and from the systematic description of Palaeozoic Echini. The geological distribution of the several groups of Echini as given in the table (p. 209) is taken from the systematic part of this memoir excepting the groups of the Centrechinoida and Exocycloida which are taken from Duncan (1889a).¹

The most primitive type of Echini, I believe emphatically, is *Bothriocidaris*. This view is based on the simplicity of its structure, and especially on the close comparison of this structure with that seen in the very young of all geologically later Echini known and the youthful characters retained at the ventral border in the adults of many types. In *Bothriocidaris*

¹ I differ from Duncan in regard to the Hemicidaridae which I date from the Trias whereas Duncan (1889a, p. 50) says that Hemicidarid occurs in the Zechstein. Dr. Bather (1909a, p. 250) expresses himself very positively that none of the Ectobranchiata appear before the Trias and I prefer to follow this most accurate authority. I differ also in extending the Holoetypina only to the Eocenc, as the Recent Pygastrides (Duncan, 1889a, p. 138) is very doubtful.

Based on the Structure and Development of the Ambulacra, Interambulacra; Form and Sculpturing of the Test; Imbrication in the Corona; Basicoronal Plates; Ventral Resorption of Corona; Ocular and Genital Plates; Periproct, including its Structure and Position; Peristome; Aristotle's Lantern; Perignathic Girdle; Spines and Tubercles; Stewart's Organs, Gills, and Sphaecidia. The relative importance of these several parts naturally differs in different groups of Echini.

(Plate 1, fig. 1), in the corona each ambulacrum consists of two columns of high hexagonal plates, each with two pores, superposed, surrounded by a peripodium, and situated in the middle of the plate. Such a structure is not known in any other adult regular echinoid, but is almost identical with that seen in young *Goniocidaris* (Plate 2, figs. 1-3), *Strongylocentrotus* (Lovén, 1892), and *Phormosoma* (Mortensen, 1904, p. 54). Each interambulacrum of *Bothriocidaris* consists of a single column of plates, which is represented by a single plate at the ventral border of the interambulacra in the young of all other Echini (*Goniocidaris*, Plate 2, fig. 1; *Strongylocentrotus*, Plate 3, fig. 11; *Phormosoma*, Plate 3, fig. 10). This single plate is also seen in adults where resorption has not removed the base of the corona, as in the Palaeozoic *Hyattechinus rarispinus* (Plate 23, fig. 1), *H. pentagonus* (Plate 25, fig. 1), *H. beecheri* (Plate 26), *Perischodorus* (Plate 64, fig. 2). Again, the single ventral plate is seen in adult Recent *Phormosoma* (text-fig. 43, p. 80), *Arbacia* (text-fig. 227, p. 193), in the Triassic *Tiarechinus* (text-fig. 31, p. 70), and in nearly all clypeastroids and spatangoids (text-figs. 27-29, p. 70, and 52, 54, p. 80; Plate 3, fig. 15). It seems that there is ample proof that the interambulacrum begins with a single plate, as shown by Lovén (1874), and Mortensen (1903) in *Hypsiechinus* (Plate 3, fig. 6). This structure with less evidence I correlated (Jackson, 1896, p. 233) as a stage in development with the single column of plates in *Bothriocidaris*, naming it the *protechinus* stage. As Palaeozoic types with many columns of interambulacral plates begin at the ventral border, the young, with a single plate representing a single column, and later add their several columns during development (Plate 26), it seems that *Bothriocidaris* throws great light on the numerous columns there existent (p. 64).

In *Bothriocidaris* a row of primordial ambulacral plates forms a continuous ring around the mouth, as in all succeeding regular Echini, and they are relatively large, as in the young of modern Echini, *Goniocidaris* (Plate 2, fig. 1). In *Bothriocidaris* a second row of plates surrounds the first, completing the peristome. This second row was probably derived by flowing down from the corona, and is closely comparable to the second stage in development of *Phormosoma* (Plate 3, fig. 10), as pointed out by Mr. Agassiz (1904, p. 79). A striking feature of *Bothriocidaris* is the great size of the oculars and the very small genitals (Plate 1, fig. 2). This may fairly be compared with the similar condition in very young *Echinus microtuberculatus* (Plate 3, fig. 5), as shown by Bury (1895), though the adult of the same species has large genitals which exclude the oculars from the periproct. The most difficult thing to account for in *Bothriocidaris* is the fact that the teeth seem to be radial in position, as discussed (p. 242).

Of the three species of *Bothriocidaris*, the salient features are, briefly, as follows. In *B. archaica* sp. nov. the oculars meet in a continuous ring with genitals dorsal to the same (Plate 1, figs. 1, 2), interambulacral plates bear spines. In *B. pahleni* Schmidt (Plate 1, figs. 3-6), part of the genitals lie dorsal to the oculars, and part separate the oculars, reaching the interambulacra; interambulacral plates are without spines. In *B. globulus* Eichwald (Plate 1, figs.

7-9) all of the genitals separate the oculars and meet the interambulacra; interambulacral plates bear spines. These several species occur in the Ordovician of Russia (p. 238).

The feature of Palaeozoic Echini is that they have more than two columns of plates in each interambulacral area. This is true of all known forms excepting *Bothriocidaris* and *Miocidaris* as far as the latter occurs in the upper Palaeozoic. Gregory (1897), Sollas (1899), and others have assumed that the most primitive form of Echini had many columns of interambulacral plates in an area, and several authors have considered *Palaeodiscus* as the most primitive known type. On this basis evolution would entail a loss of such parts, as our modern types all have two columns of interambulacral plates in an area. The evidence of development and adult structure is opposed to this view. At the ventral border of the young of all known modern types, and at the ventral border of the adult where not removed by resorption, we find a single primordial plate in each interambulacral area succeeded in the second row by two plates. There is no evidence in development of a larger number of columns dropping out to two in any known living form, or indeed, in any fossil form excepting as seen in senescence (*Perischoecidaris*, Plate 65, figs. 1, 2; Plate 67, figs. 2, 3), and in the little known *Tetracidaris* of the Cretaceous. I, therefore, consider the Echini usually classed as the *Euechinoida*, with a geological range from the Lower Carboniferous to Recent inclusive, and comprising the orders *Cidaroida*, *Centreechinoida*, and *Exocycloida* as next related to *Bothriocidaris*. This view is based on structure and development. I am well aware of the intervening geological gap, but can only appeal to the rarity of all forms in the Silurian and Devonian to account for the absence of intermediate types. While the Palaeozoic orders *Echinocystoida* and *Perischoecchinoida* are not considered as in the direct line of ancestry of modern forms, they yet show many primitive characters, especially as regards the peristome and lantern, which can well be compared with the condition in the young of later types.

The order *Cidaroida* is placed as directly derived from the *Bothriocidaroida* without known intermediate forms. The *Cidaridae* as regards the structure of the young and adult are the least removed from *Bothriocidaris* of any known echinoid, living or fossil. The young (Plate 2, figs. 1-3, 6) have high hexagonal ambulacral plates with the pores of the pore-pairs superposed. Each interambulacrum has a single plate ventrally, succeeded by two plates in the next row. The peristome has a single row of primordial ambulacral plates which are like those of *Bothriocidaris* excepting that in that type there are two peristomal rows. The base of the corona has not yet been resorbed, exactly like adult *Bothriocidaris*. In young *cidarids* the genitals are large and oculars small and exsert, unlike *Bothriocidaris*. The young lantern is inclined (Plate 2, fig. 17), with deep foramen magnum, long interpyramidal muscles (Lovén, 1892) as in the *Perischoecchinoida*, and the lantern muscles are attached directly to the basi-coronal interambulacral plates without apophyses (Lovén, 1892), as is the apparent condition in the *Perischoecchinoida* (text-fig. 221, p. 193).

Adult cidarids differ from the young principally in having low instead of high ambulacral plates, the ventral border of the corona resorbed, many rows of ambulacral, also (with rare exception) interradial non-ambulacral plates in the peristome. Many rows of ambulacral peristomal plates is distinctly a Palaeozoic character (Plate 23, fig. 1), and some genera as *Archaeocidaris* have non-ambulacral plates as well. The oculars of adult cidarids may be all exsert as in the young, or one or more to all insert, as shown here. The periproct is plated with numerous heavy plates as in the *Perischoechinoida*. The lantern of the adult is nearly vertical (Plate 2, figs. 7-10), instead of inclined, with a very shallow foramen, and short interpyramidal muscles. The perignathic lantern muscles are all inserted on the elevated apophyses, a feature peculiar to this order only (text-fig. 222, p. 193). The absence of pits in the top of the pyramids is a feature like the *Perischoechinoida* but unlike the *Centrechinoida*. Teeth are grooved as in the *Echinocystoida*, *Perischoechinoida*, and *Aulodonta*. Primary spines are strikingly developed, naked of epidermis, with a cortical layer and a collar about the base, thus differing from the next order. The presence of frondescent Stewart's organs and the absence of peristomal gills and sphaeridia are distinctive characters of the order. The *Cidaroida* present distinctly a combination of Palaeozoic with modern characters.

Apparently only two species in the Palaeozoic are definitely referable to the *Cidaridae*, the Lower Carboniferous *Miocidaris cannoni* sp. nov. from America (p. 247), and the Permian *Miocidaris keyserlingi* (Geinitz) from Europe (p. 245).

The *Centrechinoida* as an order differs from the *Cidaroida* in that the ambulacral plates are usually compound; the peristome (excepting the *Echinothuriidae*) has only one row of primordial ambulacral plates, with non-ambulacral plates. The lantern has a deep foramen magnum, the tops of the pyramids are pitted, and auricles are developed, on which are inserted the retractor muscles of the lantern. Peristomal gills and sphaeridia are developed. The young of the *Centrechinoida* (Plate 3, figs. 9-11) make a close approach to cidarids in having simple ambulacral plates, and large central spines and tubercles in the middle of the interambulacral plates. Further, the young have a single primordial interambulacral plate in each area, peristome covered with ambulacral plates only, inclined lanterns with long interpyramidal muscles recalling young cidarids, and the characters seen in the adults of certain Palaeozoic types, as previously discussed. Of the three suborders of the *Centrechinoida*, the first has the most characters like the *Cidaroida*, and the last has the fewest (p. 183).

The suborder *Aulodonta*, while having the characters of its order, makes an approach to the *Cidaroida* in that the teeth are grooved, epiphyses narrow (text-fig. 211, p. 184), and primary tubercles perforate. Some members also approach the *Cidaroida* in possessing simple ambulacral plates, or Stewart's organs, or many rows of ambulacral plates in the peristome.

The *Hemicidaridae* being wholly a fossil group, some characters are wanting. The peristome is unknown. They are primitive in that oculars are mostly all exsert, regressive in that

Hemicidaris in the upper half of its test has returned to simple ambulacral plates. In my tables of ocular plates (pp. 154-159) Duncan is followed in the grouping of fossil genera in families, and it is possible that some genera placed in this family may have other affinities. The plates are thick and most genera have perforate tubercles.

The Aspidodiadematae are essentially characterized by simple ambulacral plates, large primordial ambulacral plates which nearly cover the peristome (text-fig. 51, p. 80), and a very large apical disc, all of which are primitive characters. There are very wide insert oculars (text-fig. 80, p. 104). The test is thin and fragile.

The Centrechinidae have compound ambulacral plates of usually three elements each. The Mesozoic species have relatively thick plates, not imbricate, oculars usually all exsert. The living species have thin tests more or less imbricate, three or more oculars usually insert (text-figs. 81-99, pp. 105-109); while the sequence of incoming of oculars is typically I, V, IV, II, it is not rarely (*Centrechinus setosus*) I, V, IV, III, a feature rare in the order as a whole, but a typical variation of many cidarids (p. 96). There are only ten primordial ambulacral plates of moderate size on the peristome with non-ambulacral plates (Lovén, 1892, Plate 12, figs. 153, 154), a strong distinction from the Echinothuriidae. While the lantern is typically erect, it is inclined in *Astropyga*, as in the next family.

In the Echinothuriidae the test is remarkably thin and strongly imbricating, and ambulacral plates are compound, composed of three elements each. The primordial interambulacral plates are retained in the basicoronal row (text-fig. 43, p. 80). It is remarkable that a peristome of the size attained in this group comes about by the growth of the plates and not by resorption of the base of the corona. Perhaps the most distinctive character of the family is the fact that the peristome is plated with many rows of ambulacral plates only, a feature rarely seen in the Cidaroida and in no other post-Palaeozoic group; but a character of many Palaeozoic genera, as *Palaeodiscus* (Plate 18, fig. 2), *Hyattechinus* (Plate 23, fig. 1), and *Lepidesthes* (Plate 68, fig. 3). Mortensen (1904, p. 53) on the strength of my observations classed the Echinothuriidae with the Lepidocentrinae because of the similarity of the peristome. I cannot agree with this view; the ambulacra and interambulacra differ radically from those of the Lepidocentrinae. In addition, the auricles, peristomal gills, and pits in the top of the pyramids class this family with the Centrechinoida and with close affinities to the Centrechinidae excepting for the peristome. This is the relationship recently adopted by Messrs. Agassiz and Clark (1909).

The character of the peristome with many rows of ambulacral plates only may perhaps be best considered a localized reversion, or parallelism to some ancient type. Such is seen, in fact, in the young of all regular Echini where the peristome for a time is covered with ambulacral plates only. The oculars of the echinothuriids are exsert in the young (Plate 3, fig. 8), but in the adult are all insert and often are separated from the genitals (text-fig. 170, p. 149), a

feature characteristic of this family only. The lantern is inclined, with long interpyramidal muscles (Plate 2, figs. 19-21), a feature like the Palaeozoic, and also the young of types that have erect lanterns in the adult. It may be considered a retention in the adult of a youthful character, seen also in *Astropyga*. 'Stewart's organs, more or less developed, are a feature of this family, as of the *Cidaroida*, although they differ markedly, being vermiform or sausage-shaped rather than frondescent as in the *Cidaroida*. Radial peristomal and somatic muscles (text-fig. 226, p. 193) are peculiar features of the *Echinothuriidae* and known in no other *Echini*.

The suborder *Stirodonta* differs from the *Aulodonta* in that the teeth are keeled, but agrees with it in that the epiphyses are narrow (text-fig. 212, p. 184). In some the primary tubercles are perforate as in the *Aulodonta*, but in most genera tubercles are imperforate as in all the *Camarodonta*. This group, as most others, occupies an intermediate position, possessing in some genera characters like the preceding, and in others characters like the succeeding group. Such is found to be true of any classification if the groups are at all nearly related.

The *Saleniidae* is one of the most interesting groups of *Echini*. The permanence in the adult of the suranal is one of the most striking features (text-figs. 102-105, p. 111). It may lie against genital 3 as in *Salenia* or facing ocular III (*Peltastes*), or may be one of several large plates as in some *Acrosalenias*. This is apparently the first appearance of the suranal plate in *Echini*, as discussed (p. 174). The ambulacral plates may be compound throughout, or only ventrally and simple above, indicating extreme reversion. The large primary spines and prominent central tubercle like *Cidaris* may fairly be considered a retention in the adult of characters common to the young of the whole order, indicating with the simple ambulacral plates, when they occur, a reversionary rather than a progressive type. The retention of a single madreporic opening on the proximal side of genital 2 (Plate 4, figs. 1, 2) is a fact in accordance with the same line of reasoning. Ocular plates are exsert or reach the periproct in the sequence I, V, IV, II, III, a contrast to the *Arbaciidae* where the sequence is V, I, IV.

The *Phymosomatidae* Mortensen (1904, p. 55) classes with the *Saleniidae* and *Arbaciidae*, expressing closer relations with the latter. Duncan (1889a) also places this family next to the *Arbaciidae*. Ambulacral plates are compound, of five elements each in the Recent *Glyptocidaris crenulare*, or with more or fewer elements in some fossils. One or more to all oculars may be insert (text-fig. 106, p. 113). Mr. Agassiz's photographic figure (1873, Plate 7a, fig. 8) of Recent *Glyptocidaris crenulare* shows ocular I only insert. This character, with the somewhat prominent suranal plate opposite genital 3 in the figure cited, inclines one to affiliate the family rather more closely with the *Saleniidae* than the *Arbaciidae*. The teeth are keeled, epiphyses narrow, and spurs from the dorsal tips of the pyramids support the teeth as in *Stomopneustes* (Plate 4, figs. 8-10). This structure is peculiar to these two families only, as far as known.

The *Stomopneustidae* contains only the *Stomopneustes variolaris*. This genus has been classed with the *Echinometridae*, but Mortensen (1903, p. 133) separated it as a distinct family

on account of differences in spicules of the tube-feet which are very large and peculiar, and on differences of the pedicellariae. It differs from the Echinometridae also in that the oculars enter the periproct in the sequence I, V, IV (p. 113), not V, I, IV, as in that family. The most important character, however, is that the teeth are keeled and epiphyses narrow, not meeting in suture over the foramen magnum (Plate 4, figs. 8-10). Other important peculiarities exist as described (p. 186). The character of the lantern places this genus and family as a member of the Stirodonta. Its affinities are nearest to the Phymosomatidae as indicated by spurs from the dorsal tips of the pyramids, which support the teeth (Plate 4, figs. 8-10). The ambulacral plates are composed of three elements each, and where fully developed, as at the mid-zone, four or five plates are combined and grown over by a large primary tubercle, a very striking character. The periproct has numerous small plates, as in Phymosoma. The ocular plates of the bivium are typically insert in *Stomopneustes variolaris*, but I only or I, V, IV may be insert as described (p. 113). Also, as an aberrant variation, three specimens in a total of 64 have oculars I, V, II insert. This is an essential character of the Echinidae and Strongylocentrotidae, and suggests a connection between the families. The small suranal plate of *Glyptocidaris crenulare*, as figured by Mr. Agassiz (1873, Plate 7a, fig. 8), suggests the same affinity, and it seems that in one of these two families may lie the ancestral stock of the Echinidae and allies.

Of the Arbaciidae the most striking feature is that there are only four, or five, nearly equal plates in the periproct, a feature otherwise known only in *Parasalenia*. Another important feature not so readily ascertained is the retention of the primordial interambulacral plates in the basicoronal row, as pointed out by Mr. Agassiz (1904, p. 54). A third unusual character is that ocular plates, when they enter the periproct, do so in the sequence V, I, IV (p. 158). This is known elsewhere only in the Echinometridae, as here shown. The auricles exist as widely separate styloid processes (text-fig. 227, p. 193) or slightly arched and joined by suture (text-fig. 228). Tube-feet are dorsally modified as ambulacral gills in *Arbacia* (A. Agassiz, 1872, p. 264). In the genera *Habrocidaris* and *Podocidaris*, as shown by A. Agassiz and Clark (1908, p. 77), and *Pygmaeocidaris*, as shown by Döderlein¹ (1906), the primordial interambulacral plate is retained as in *Arbacia*.

The suborder Camarodonta may be considered the most specialized of modern regular Echini on the basis of the lantern, and also in various genera by the sculptured test, the degree of specialization of the ambulacrum, peristome, perignathic girdle, or the elliptical form through a sidewise axis. The essential feature is the fact, that while the teeth are keeled as in the last

¹ Döderlein figures (1906, p. 184, fig. 36e) a third median plate in the third coronal row of *Pygmaeocidaris*. As this genus so closely resembles *Habrocidaris*, in which there is a median tubercle but no median third plate, it is possible that Döderlein was misled in introducing the sutures of this plate, a point difficult to ascertain in such a small specimen (4.8 mm.) as he had. If Döderlein is correct, it is a unique case in the Centrechinoida.

suborder, the epiphyses are wide and meet in a medium suture over the foramen magnum (text-fig. 213, p. 184; Plate 5, fig. 2). The epiphyses further develop crests that serve as supports for the upper part of the tooth. These features are known in no other Echini and express the fullest differentiation attained in the lantern of regular Echini (p. 187).

In the Temnopleuridae, the circular form of the test, the ambulacral plates of three elements each, with the curious pitting or sculpturing developed on at least the upper part of the test are the most distinctive features. The peristome is mostly naked except for the primordial ambulacral plates. Of *Pleurechinus doederleini*, Mortensen (1904, p. 78) says that there are only five, instead of ten, buccal plates, a unique character. This is a very remarkable departure, as the ambulacrum, both in the peristome and in the corona of Echini, so constantly consists of a right and a left half for each area. The ocular plates are mostly exsert in modern types, a primitive character, but one or more are said to be insert (Duncan, 1889) in some fossil types. In the Cretaceous *Glyphocyphus radiatus* all oculars are insert, p. 117. This family on account of its peculiarities represents probably a side branch rather than the basal series of its suborder.

The Echinidae is a large family including many genera and species; the test is circular or slightly pentagonal; ambulacral plates have three elements each. Plates with two elements each occur in *Echinus affinis*, but this is exceptional, and they exist dorsally only (p. 118). The peristome has ten primordial ambulacral plates of moderate size (Lovén, 1892, Plate 12, fig. 156) with more or fewer large or small to granular non-ambulacral plates. Exceptionally there is a dense covering of non-ambulacral plates (*Toxopneustes*, text-fig. 57, p. 84). The oculars may be all exsert, or ocular I, or very frequently I, V, or rarely I, V, IV may be insert as a species character; as progressive variants, oculars I, V, IV, II, or all plates may be insert. The range of variation is wide in many species, but with rare exceptions oculars reach the periproct in the sequence I, V, IV, II, III (text-figs. 115-127; pp. 160, 161). The commonest aberrant variant for oculars is for I, V, II to be insert, a combination seen only in this family, the Strongylocentrotidae, Stomopneustidae, and Saleniidae (p. 164). In *Gymnechinus* (p. 120) typically an abnormal arrangement of oculars occurs as described.

The periproct is plated with many larger or smaller plates, and in adults frequently a somewhat larger plate, which is apparently the suranal, lies against or near genital 3 (text-fig. 122, p. 122). The size which renders this plate distinguishable is subject to much individual variation. It is markedly developed in some, as *Toxopneustes variegatus*. Of the perignathic girdle the auricles are moderately developed and commonly meet in an arch over the ambulacrum; apophyses are usually only slightly developed.

The Strongylocentrotidae (Gregory, 1900, p. 313) includes the large genus *Strongylocentrotus* and a few others. The test is circular as in the Echinidae, but, with the exception of some species of *Echinostrephus*, there are from four to ten elements to an ambulacral plate. As in the Echinidae, oculars may be all exsert or otherwise reach the periproct in the sequence

I, V, IV, II (text-figs. 128-153). Many species typically have the bivium insert, and one, *Strongylocentrotus gibbosus* (p. 145), typically has an aberrant arrangement of oculars. *Strongylocentrotus albus* is peculiar in having frequent and also very rare forms of aberrant arrangement of ocular plates (pp. 127, 162, 164).

The Echinometridae, as here restricted, includes genera which are elliptical through a sidewise axis, not through III, 5. As a secondary character, the ocular plates, when reaching the periproct, do so in the sequence V, I, IV, not I, V, IV, as in the Echinidae and Strongylocentrotidae. This sequence is strongly held as shown in the table (p. 163), but occasionally ocular I comes in first as a variant. These characters eliminate Strongylocentrotus and its allies, which have usually been included here, but which I include in Gregory's (1900) family Strongylocentrotidae placed next to and associated with the Echinidae. The Echinometridae besides the above have in some genera other striking and very specialized characters. In *Echinometra lucunter* the auricles are extraordinarily developed as high spoon-shaped arches (text-fig. 230, p. 193). In *Heterocentrotus* the primary spines attain excessive size and bulk, and in another direction the spines of *Colobocentrotus* are most abbreviated, truncate; and in *C. atratus* the spines are polygonal from mutual pressure, so as to resemble angular plates.

The Exocycloida present a remarkable series of forms of Echini, all characterized by having the periproct eccentric in interambulacrum 5. Assuming a monophyletic origin for the group, the three suborders present a striking series of structural departures from the regular Echini from which they doubtless originated. Considering the characters of the group as a whole in brief, the compound ambulacral plates and peristomal gills of the Holoctypina and the auricles of that group and the Clypeastrina, the existence of keeled teeth, where teeth are known, and the presence of sphaeridia, are all characters which unquestionably associate the Exocycloida with the Centrechinoida and not with the Cidaroida, where these structures are non-existent. Mr. Agassiz (1909) has shown that in the young of the spatangoid *Echinoneus* a well developed lantern exists. This discovery is of the greatest interest and importance, as previously teeth were unknown in this group. On examining his figures and description, it is seen that the lantern is erect, teeth are keeled and epiphyses narrow, not extending over the foramen magnum. Further, the interpyramidal muscles are short, the protractor and compass muscles are inserted on the primordial interambulacral plates, and the retractors are inserted on the auricles which are situated on the ambulacra. These details are shown more fully by Westergren (1911), in a monograph on the genus *Echinoneus*, which death prevented Mr. Agassiz from writing. Looking back to the Centrechinoida, we find that this type of lantern exists only in the suborder Stirodonta. Further, the attachment of muscles, as stated, occurs only in Arbacia and probably other members of its family. Looking at the matter from the view-point of Arbacia, in that genus the teeth are keeled, epiphyses narrow (text-fig. 212, p. 184); the primordial interambulacral plates are retained in the basicoronal

row; auricles exist as usually separate styles (text-fig. 227, p. 193); ambulacral tube-feet dorsally are modified as ambulacral gills, and locomotion is effected in considerable part (A. Agassiz, 1872, p. 264) by the spines. Any one of these characters might well be a case of parallelism, but the sum of them gives strong evidence of kinship with the Exocycloida. I therefore consider the Exocycloida as connected with the Arbaciidae, probably through some early common ancestral stock.

The suborder Holoctypina is nearest akin to the Centrechinoida as it possesses compound ambulacral plates and peristomal gills. The ambulacra are not petaloid dorsally as they usually are in clypeastroids and spatangoids. The lantern is inclined with moderately deep foramen magnum, and the wings of the pyramids are horizontally striated for attachment of interpyramidal muscles as in regular Echini (Lovén, 1892). The teeth are narrow, elongate, and keeled, and the epiphyses are large, but narrow (Hawkins, 1909). These characters make a near approach to those of the Stirodonta, but in part are like those of the clypeastroids. In addition, in the Holoctypina auricles exist on the ambulacra and there are low interambulacral apophyses, both of which occur in the Centrechinoida, but auricles only exist in the clypeastroids. In the Holoctypina the base of the corona is only partially resorbed so that one or more primordial interambulacral plates are retained in the basicoronal row of the adult (Lovén, 1874). In this suborder there are usually five genital plates with the madreporic pores in genital 2, but in genital 5 there is no pore (text-fig. 171, p. 149), or genital 5 may be absent. The test is usually circular and not specially modified as in the two following suborders.

In the suborder Clypeastrina the test is more or less flattened to discoid, circular, pentagonal, or other shape, and elongate and bilaterally symmetrical through III, 5. Internal pillars and stalactitic growths are peculiar to the group, also lunules, or reëntrant emarginations may develop. Ambulacral plates are simple with the typical ambulacral pores limited to a petaloid area dorsally; ventrally there are numerous very minute pores, described by Mr. Agassiz (1874, p. 695). They are so small as to be recognizable only with difficulty. Both the primordial ambulacral and interambulacral plates are in the basicoronal row (text-fig. 52, p. 80) a character not known in regular Echini at any stage in life. Rarely (Arachnoides, p. 72, according to Lovén, 1874), one interambulacral plate is pushed dorsally and the other four are resorbed by intracoronal resorption so that the basicoronal row may be composed of ten ambulacral plates only, a unique condition for Echini. The peristome is leathery without plates, as far as I have been able to ascertain, a condition unknown in other Echini. Oculars and genitals are fused into a mass; comparable to this is the partial fusion of genitals typical of some spatangoids, and the partial fusion of genitals or genitals and oculars occurring as variants in regular Echini (p. 167). There are four or five genital pores, but the posterior is usually wanting. In *Laganum diploporum*, described by Messrs. Agassiz and Clark (1907), curiously enough there are six genital pores, two being in area 5. The lantern is usually

procumbent (text-figs. 214-216, p. 184) though inclined in *Echinoecyamus* (Lovén, 1892). The teeth are keeled, foramen magnum shallow, epiphyses small and narrow, brace small, wanting in *Laganum* (Lovén, 1892), compasses wanting. The pyramids are more or less highly modified (least in *Echinoecyamus*, Lovén, 1892) with wing-like lateral expansions and without ridges for the attachment of interpyramidal muscles. The perignathic girdle consists of auricles only, which are situated on the ambulacral plates (text-fig. 231, p. 197) as in the *Centrechinoida*, or may be transferred to the primordial interambulacral plates (text-fig. 236, p. 197), as shown by Lovén (1892). Each pair of auricles bears one or two pairs of retractor muscles, and in addition one pair of protractors. This last is a peculiar feature of the group, as in all other Echini with lanterns the protractors are inserted on the interambulacral plates, or on apophyses arising from the same, but not on auricles. Respiration is apparently by ambulacral gills only. Sphaeridia are situated in enclosed pits (Lovén, 1874).

The suborder Spatangina is characterized by tests which are conical, heart-shaped, or of various forms, often extraordinary (*Pourtalesia*), but bilaterally symmetrical through III, 5. The ambulacral plates are simple and the areas are usually petaloid dorsally. There may be two pores or one to a plate, or plates may be in part imperforate. The plates may be low, or high, and of very specialized form, especially in the bivium ventrally. Plates, especially in ambulacrum III, may be high, nearly or quite hexagonal in form, with pores superposed in the middle of the plate (text-fig. 8, p. 54), a feature not seen in the adults of other forms since the Ordovician *Bothriocidaris*, though common in the young of regular Echini. The primordial ambulacral and interambulacral plates are typically in the basicoronal row (Plate 3, fig. 15), but, in the shifting of parts, one or the other may in part be pushed dorsally. The base of the corona is apparently never resorbed by the advance of the peristome, which latter is usually densely covered with small non-ambulacral plates (text-figs. 27-28, p. 70, and 54, p. 80). Ocular plates may be all exsert, that is, do not reach the center line, or oculars I, V, or I, V, IV, or I, V, IV, II may be insert (text-figs. 172-175, p. 149). In certain specialized types, as seen in some species of *Pourtalesia* (Lovén, 1883; A. Agassiz, 1904), the oculars are apparently partially or wholly absent in adults. Four genitals are typically present, but 5 is absent and more genitals may be wanting. Genitals 2, 3 may be typically fused (*Cystechinus*, A. Agassiz, 1904), as seen in variants of regular Echini (p. 167). The madreporic pores are in genital 2 or extend to 3 where these two plates are fused. An extension to 3 is a common variant in some regular Echini (p. 172). Genital 2 may be much enlarged and extended posteriorly so as to reach interambulacrum 5 (text-fig. 173, p. 149). The lantern is wanting in adults, but occurs in young *Echinoneus* (pp. 189, 217), as shown recently by Mr. Agassiz (1909). Spines are short and undifferentiated, or may be highly produced and with marked areal differentiation. Tubercles in some genera are subject to much areal differentiation, making patterns on the test. The primary tubercles in *Metalia*, *Meoma*, and *Brissus* are perforate and crenu-

late, and in *Metalia* even the secondary tubercles are perforate. This perforate character is a parallelism or a reversion to a feature typical of Palaeozoic species, the *Cidaroida* and *Aulodonta*, but is not known in other regular Echini excepting a few of the *Saleniidae*. Respiration is apparently by ambulacral gills only. Sphaeridia are present.

All the orders thus far considered have two columns of plates in each ambulacral area; and one column (*Bothriocidaroida*) or two columns (*Cidaroida*, *Centrechinoida*, *Exocycloida*) in each interambulacral area. In the latter the two columns succeed a single column represented by a single plate in the basicoronal row, seen in the young and also in the adult if not resorbed. In succeeding orders we find two or more columns of ambulacral plates, and three or more columns of interambulacral plates in each area respectively, and on this basis they are considered a further remove from the primitive than any of the above types (p. 70).

Of the *Plesiocidaroida* the type is *Tiarechinus*, which presents certain extraordinary characters as shown by Lovén (1883). The ambulacra in each area are composed of two columns of low simple plates. The interambulacra in each area retain the primordial interambulacral plates in the basicoronal row, but in the second row there are three plates (text-fig. 31, p. 70). For a row of three plates to follow immediately the primordial interambulacral plate of the first row is a character known in no other Echini. In *Tiarechinus* the three plates of the second row are elongate, reaching the apical disc, so that each area consists of but two rows of plates, a unique condition. The genitals are exceptionally large, nearly covering the dorsal field of the urchin, and oculars are small and strongly exsert. With present knowledge it is not closely affiliated with any other group. The three columns of plates in an interambulacral area, the retention of the primordial interambulacral plates, and the imperforate and peculiarly distributed primary tubercles are all objections to including *Tiarechinus* in the *Cidaroida* as done by Bather (1909a, p. 66).

The Palaeozoic Echini included in the orders *Echinocystoida* and *Perischoechinoida* structurally are more removed from the primitive as regards the ambulacrum and interambulacrum than any Recent form. Further, there is no evidence in the development of modern types that they were derived from these more complex forms. Following the facts there is no alternative, as I see it, except to consider the Palaeozoic genera of the *Echinocystoida* and *Perischoechinoida* as structurally differentiated on independent lines from later known forms and on those lines further removed from the primitive than are the types now living. A somewhat comparable case is seen in Cephalopoda in which the extinct Devonian to Cretaceous *Ammonoidea* are further removed structurally from the primitive Cephalopoda than are the species of living *Nautilus*.

Certain broad characters of these Palaeozoic orders may be considered first as they are features of the group as a whole and can thus be disposed of and save repetition. Ambulacral plates are always simple, with two pores each. There may be two columns of such plates in

each area or more than two up to twenty, but with an equal number in each half-ambulacrum. The primordial interambulacral plates may be retained in the basicoronal row, or may be resorbed in the advance of the peristome. There are three or more, usually more, columns of plates in each interambulacral area, and there may be as many as fourteen, the highest number at present known. The plates may be imbricate or not, but when imbricate, the ambulacrals imbricate adorally and the interambulacrals aborally and from the center laterally and over the ambulacrals (text-figs. 32-38, p. 75). The primordial ambulacral plates are situated on the peristome around the mouth as in *Cidaris*, as known in some types and inferred in others. Succeeding these on the peristome there are many rows of ambulacral plates only, extending to the corona, or in addition there may be non-ambulacral plates in certain genera. In the Echinocystoidea the apical disc is doubtful, but in the Perischoechinoida it is small proportionately to the diameter of the test, a progressive character (Plate 55, figs. 2, 3). Oculars are typically all insert, but rarely one or more to all may be exsert. Ocular pores are rarely visible. Genital plates are of moderate size and have from two to ten or eleven pores each. In one species only (*Lepidechinus tessellatus*, Plate 63, figs. 7, 8) there is a single genital pore in a plate as far as preserved. A madreporite is only occasionally recognizable. The periproct where known is covered with many thick plates as in *Cidaris*, and no suranal is recognizable. The lantern is inclined (Plate 27, figs. 4-6) like that of the young of modern regular Echini, and as in that group, is composed of forty pieces. The teeth are grooved as in the Cidaroida and Aulodonta. The epiphyses are narrow; brace and compass as in modern forms. The foramen magnum is moderately deep and the lateral wings of the pyramids have ridges for the attachment of interpyramidal muscles which were relatively long. The dorsal face of the pyramids is smooth as in the Cidaroida, not pitted as in the Centrechinoida. No perignathic girdle is known and lantern muscles were apparently attached directly to the base of the interambulacral plates (text-fig. 221, p. 193), as in young *Cidaris*. There may be primary spines with secondaries, and the tubercles of primary spines perforate; or there may be secondary spines only, the tubercles of which are imperforate. Respiration was quite likely effected by Stewart's organs, as in the Cidaroida. There certainly were no peristomal gills as in the Centrechinoida. Sphaeridia are unknown.

The Echinocystoidea as an order is characterized by the fact that the anus was apparently eccentric in an interambulacrum. The material is not well preserved and is imperfectly known. There are two or four columns of ambulacral and eight or nine columns of interambulacral plates in each area respectively. The plates are thin and imbricating. What the relations of this group are is uncertain, though it has certain approximations to the Lepidocentridae and may be an offshoot from a common early stock. As an irregular group in the Palaeozoic it is considered first in order to dispose of it (p. 250).

The Palaeodiscidae as a family is the least specialized of its order as there are only two

columns of plates in an ambulacral area. These plates are wide and low with two pores each. The pores are not wanting ventrally, as stated by Gregory (1897). There are apparently eight or nine columns of irregular interambulacral plates in an area and the primordial interambulacral plates are in the basicoronal row. The peristome is covered with ambulacral plates only, and the lantern, as shown by Sollas (1899; my Plate 18, fig. 5), has the usual features of Echini. The anus is apparently eccentric in an interambulacrum, as shown by Spencer (1904), but ocular and genital plates are unknown. An attempt has been made to correlate the only species in this family with Asteroidea and to regard it as a primitive echinoid, which I believe is unreasonable as considered under the description of the species. There is only one genus and species (*Palaeodiscus ferox*) from the Lower Ludlow, Silurian of England (Plate 18, figs. 1-5), (p. 250).

In the Echinocystidae the ambulacra consist of four columns of plates in each area, being evidently an independent taking on of this character of many columns, which is a feature of the Palaeozoic. There are eight columns of plates in an interambulacral area. The anus apparently, as figured, is eccentric in an interambulacrum (Plate 20, fig. 1). There is only one genus and species which is imperfectly known: *Echinocystites pomum* Wyville Thomson from the Lower Ludlow, Silurian of England (Plate 16, fig. 4; Plate 18, figs. 6-8; Plate 20, figs. 1-4), (p. 252).

The order Perischoechinoida includes all the remaining and the best known Palaeozoic genera. In this order the periproct is within the oculo-genital ring. While in many genera there are two columns of plates in each ambulacral area, there is in other genera an excess of this number up to twenty columns, and this is the one group of Echini characterized by extreme development in this direction. The interambulacra rarely have as few as three columns of interambulacral plates in an area, usually there are more, and as an extreme, as many as fourteen occur in each area. This character of the ambulacra and interambulacra is the most striking Palaeozoic feature. Coronal plates may be imbricate or not, varying with the families; also the primordial interambulacral plates may be in the basicoronal row or resorbed, varying with families. Of course this is a rather nice point to determine as a specimen must be perfect ventrally in order to ascertain it, so that the evidence may be taken from only a few species, or even a single species in a family, and is open to correction with further knowledge. The peristome may have many rows of ambulacral plates only, the more primitive character, or may have the same with in addition some interradian non-ambulacral plates. Ocular plates are typically all insert, but in a few cases one or more to all are exsert, foreshadowing the typical Mesozoic and immature (also often adult) modern character. The genital plates are of moderate size and usually have from two to many genital pores. The madreporic pores have been rarely found, but usually are not distinguishable and perhaps were not existent in some species. The Palaeozoic periproct is well known in this order, and is practically uniform throughout,

composed of many rather thick plates close to the character of the periproct in the Cidaroida. The lantern is known well for the Palaeozoic only in this order, and is strikingly uniform in character. Mr. Agassiz (1881, p. 80) suggested and Duncan (1889a, p. 11) stated that there are passages for peristomal gills in *Archaeocidaris*, but such have not been figured. As there was no indication of such slits in the best specimens which I studied (Plate 9, fig. 6 and Plate 11, fig. 1) and as such structures are otherwise known only in the Centrechinoida and Holecypina, I think this is a mistake, and peristomal gills may be considered as wanting in *Archaeocidaris* and other Palaeozoic genera as well (p. 253).

The *Archaeocidaridae* is a family with only three genera, *Eocidaris*, *Archaeocidaris*, and *Lepidocidaris*. Eliminating *Eocidaris*, which is most imperfectly known, there are two columns of ambulacral plates and four, or six to eight of interambulacral plates in each area respectively. The plates are rather strongly imbricate, and each interambulacral plate bears a central primary perforate tubercle and large spine, also secondary spines and tubercles. The base of the corona is extensively resorbed, there being four plates in the basicoronal row in each interambulacral area. The peristome has many rows of ambulacral plates with non-ambulacral plates in *Archaeocidaris* (Plate 9, figs. 6, 7) and probably was similar though unknown in *Lepidocidaris*. The apical system is doubtfully known, which is rather remarkable with so many species. The lantern is well known in *Archaeocidaris* (Plate 12) and consists of forty pieces as in modern regular Echini (p. 254).

The genus *Eocidaris* has large interambulacral plates which bear a central perforate tubercle, as in *Archaeocidaris*; there is a scrobicular area but no basal terrace. This genus is most imperfectly known, but Bather (1909), who has studied the question and material critically, feels that it should be retained. Only one species is recognized, the Devonian *E. laevispina* (Sandberger), Plate 15, figs. 11, 12. The absence of a basal terrace, which is the essential difference from *Archaeocidaris*, could easily be accounted for by wear as it is not always observable in true *Archaeocidaris*. The young dorsal plates of *Archaeocidaris* have no basal terrace (Plate 11, fig. 2), so that a genus founded on this character should be considered the more primitive of the two (p. 254).

In *Archaeocidaris* the ambulacral plates are narrow and low, with pore-pairs uniserial (Plate 12, fig. 9). In the few species where the corona is fairly known, there are four columns of large plates in each interambulacral area (Plate 10, fig. 10). Each plate bears a large central perforate tubercle with a basal terrace and scrobicular ring (Plate 11, fig. 4). The basal terrace is so slight an eminence that it is often worn off, and this feature can only be ascertained in fairly well preserved specimens. From the center rises a primary spine of considerable size and various ornamentation; in addition, secondary and miliary spines and tubercles occur on the periphery of the plates. The young plates dorsally (Plate 11, fig. 2) are at first smooth, then an imperforate tubercle arises (as in developing plates of cidarids, Plate 3, figs. 1, 2)

but without a basal terrace, a feature which, with the perforation, developed later as the plate was pushed ventrally by younger newly added plates. The base of the corona is extensively resorbed so that several rows of plates have evidently been cut away in the advance of the peristome (Plate 9, figs. 7, 8). This is the most extensive resorption definitely known in any Echini, though it may have been as much, or more, in Recent regular Echini, where data are not available to measure the amount of resorption (p. 256).

The species of *Archaeocidaris* are numerous but are largely described from isolated spines and plates. With available material perhaps the best way to group the species is on the basis of the character of the spines, as is done under the description of species. The smooth-spined forms are considered first, as smoothness is in general a primitive character; next are grouped the species with spines bearing short small spinules, then those with long thorn-like spinules, etc., associating the species on the similarity of characters in these respects (p. 258). Only six species are known with a more or less complete test, and of these the best material occurs in *Archaeocidaris wortheni* (Plate 8, figs. 5, 6; Plate 9, figs. 6-11) and *A. rossica* (Plate 10, fig. 10; Plates 11, 12). The species of *Archaeocidaris* occur in the Lower Carboniferous, Carboniferous or Coal Measures, and Permian.

The genus *Lepidocidaris* is known only from *L. squamosa* Meek and Worthen (Plate 16, figs. 1-3; Plate 17). The ambulacral plates are not all alike, but every third plate is larger and more or less completely abuts against two smaller plates of the opposite half-area (Plate 17, figs. 1, 3, 8). There are six or eight columns of plates in an interambulacral area; these are high, rounded, with a scrobicular area, but no basal terrace. The margin is thickly studded with secondary tubercles. The primary spines are feebly striate longitudinally and very cylindrical (p. 282).

The *Lepidocentridae* is a family of Silurian, Devonian, and Lower Carboniferous Echini that have strongly imbricate plates and includes most striking and interesting species. There are but two columns of plates in each ambulacral area, and from five to fourteen columns of plates in each interambulacral area; the latter is the extreme limit of known Echini. The primordial interambulacral plates are in place in the basicoronal row (Plate 23, fig. 1), as ascertained in five species. The peristome is covered with many rows of ambulacral plates only (Plate 23, fig. 1). Oculars where known are small, all insert, and the genitals where known, are wide with many (eight or nine) genital pores (Plate 28, fig. 10). The periproct has numerous plates (Plate 25, figs. 3, 5) and an exceptionally perfect lantern is known in one species (Plate 27), presenting the typical Palaeozoic character. The spines are small, eccentrically placed primaries, with secondaries, or the latter only (p. 284).

The genus *Koninckocidaris* Dollo and Buisseret was based on *K. cotteauxi* Dollo and Buisseret, which has not been figured. The most important character is that the ambulacral plates are high, two or three equaling the height of an adjacent interambulacral plate; pore-pairs

are uniserial. The interambulacra have seven or eight columns of strongly imbricate polygonal plates in an area. As high ambulacral plates are a primitive character, *Koninckocidaris* is considered a lower genus than *Lepidocentrus* which has low ambulacral plates (p. 284).

In *Koninckocidaris cotteau* as described, two ambulacral plates equal the height of an interambulacral; there are seven columns of interambulacral plates in an area, the median column being the narrowest; spines and tubercles are of two sizes. This, the type of the genus, is from the Lower Carboniferous of Belgium (p. 285).

Koninckocidaris silurica sp. nov. (Plate 19, fig. 1; Plate 20, figs. 5, 6) has three ambulacral plates equaling the height of one adambulacral. There are eight columns of rhombic interambulacral plates in an area, the plates of column 7 in each area being very narrow in the type. This species is from the Niagara Group, of Rochester, New York, and is of interest as by far the oldest echinoid yet found in America and also the oldest known in the family (p. 285).

Lepidocentrus is characterized by relatively high spheroidal tests, ambulacral areas narrow throughout, ambulacral plates low, interambulacra with small eccentric primary and secondary tubercles. The species are from the Devonian or Lower Carboniferous, and the best known is *L. mülleri* (Plate 19, figs. 2-5; Plate 20, figs. 8-13), (p. 286).

Hyattechinus gen. nov.—This genus includes some of the most striking of known Echini. The test is depressed or flattened. Horizontally the outline is circular, pentagonal, or clypeastriform. The most distinctive character is that the ambulacra are broad, almost petaloid ventrally, narrow dorsally, ambulacral plates are low, pore-pairs uniserial. Interambulacra have from eleven to fourteen columns of plates in each area and a very accelerated development so that new columns are added early and rapidly during development. There are small primary and secondary tubercles on the interambulacral plates. As the species of *Hyattechinus* present very exceptional characters, these may be briefly stated. In *Hyattechinus rarispinus* (Hall) (Plate 21, fig. 6; Plates 22, 23) the test is nearly circular, and flattened probably as much as in Recent *Phormosoma*; ambulacra ventrally are twice as broad as dorsally, with ventral internal spurs as in *beecheri*. Interambulacra have eleven to thirteen columns of plates in each area, varying within these limits in different areas of the same specimen (Plate 23, fig. 3). This species was described as a *Lepidechinus* by Hall, but is very different from that genus. In *Hyattechinus pentagonus* sp. nov. (Plate 24, figs. 1-4; Plate 25, figs. 1-4) the test is compressed, strongly pentagonal, the most so of any known regular echinoid. Ambulacra are ventrally twice as broad as dorsally. Interambulacra have fourteen columns of plates in each area, the highest number known in any echinoid. Dorsally, the adambulacral and some additional columns drop out and therefore fail to reach the apical disc, an indication of senescence. In the remarkable *Hyattechinus beecheri* sp. nov. (Plate 24, figs. 5-8; Plate 25, fig. 5; Plate 26) the test is depressed with a flat base, moderately pentagonal and elongate, and bilaterally symmetrical through the axis of an ambulacrum and opposite interambulacrum which I take

to be the axis III, 5. This is the only known case of a regular sea-urchin with centrally placed periproct that is bilaterally symmetrical through an antero-posterior axis. The ambulacra ventrally are twice as wide as dorsally and the ventral ambulacral plates develop a series of short spurs which extend into the body of the animal. Somewhat comparable proximal growths are known in Recent cidarids (p. 61; text-fig. 224; Plate 3, figs. 12, 13), but excepting *Hyatt-echinus* are unknown in other Echini. There are eleven columns of plates in each interambulacrum in *beecheri*. The plates by their incoming show an accelerated development, and dorsally the adradial columns and some others drop out, showing senescence. The only known specimen is an internal mold so that the exterior of the plates is unknown, yet so perfect is the specimen that it is represented spread out by the Lovén method (Plate 26), (p. 291).

Pholidechinus gen. nov. is known only from a single species, *P. brauni* sp. nov. (Plates 27, 28). The test is high and spheroidal, ambulacra narrow throughout; at the mid-zone alternate plates are somewhat pinched off at the suture with the interambulacrum, by the broadening of the plates between. Occasionally a plate is quite cut off from the interambulacrum and thus becomes occluded, but this is exceptional. There are nine or ten columns of plates in each interambulacral area. The plates are scale-like and imbricate strongly. Spines and tubercles are secondaries only, on both ambulacra and interambulacra. Genitals are very wide with many genital pores. A very perfect lantern is known, as figured (p. 299).

The family of the Palaeochinidae (commonly known as the Melonitidae) contains the most species, and as a whole is the best known of the Palaeozoic groups of Echini. The test is spheroidal or occasionally elliptical and in one species obovate. There are from two to twelve columns of plates in each ambulacral area according to the genus or species. It must be urged that this character should be ascertained at or near the mid-zone, as ventral or dorsal to this zone the number of plates may differ (text-fig. 237, p. 231), and it is at this area that the full differential specific characters are evinced, as elsewhere discussed (p. 55). In the interambulacra there are from three to eleven columns of plates in each area varying with the species, also varying somewhat in the species and even somewhat in different areas of the same individual. The plates of the corona are not imbricate, but in all species the ambulacral plates bevel over the interambulacral on the adradial sutures (Plate 38, fig. 9). A reverse condition exists in all Echini with imbricate plates, for in these the interambulacrals are beveled over the ambulacrals on the adradial suture (text-fig. 32, p. 75). Coronal plates are very thick, more so than in any other group of Echini, the thickness often exceeding the width or height of a plate, a distinctly specialized character. The primordial interambulacral plates are resorbed, and apparently these only, as there are two interambulacral plates in each interambulacral area in the basicoronal row (text-fig. 25, p. 70). The peristome is known only in *Melon-echinus multiporus* (text-fig. 48, p. 80). On the basis of this species there are many rows of ambulacral with some interradian non-ambulacral plates on the peristome. Ocular plates are

imperforate in the known species. They are typically all insert, or reaching the periproct, but exceptionally one or more to all may be exsert (Plate 33, figs. 11, 12). Genitals have from two to five pores each, and a madreporite is rarely recognizable (text-fig. 243, p. 331). The periproct is plated with numerous thick plates (Plate 34, fig. 6), as in the Cidaroida, but these plates are rarely preserved. The lantern is imperfectly known, but has the essential Palaeozoic characters as far as preserved. The spines in the whole family are essentially alike, small secondaries on ambulacral and interambulacral areas; tubercles are imperforate and evenly distributed over the corona (Plate 61, fig. 8). The existence of secondary spines and imperforate tubercles only may both be considered specialized characters. One species, *Maccoya phillipsiae*, is said to be Silurian, but all others in the family are Lower Carboniferous (p. 302).

The family characters are of course understood in the brief description of generic characters given here. *Palaeochinus* M'Coy has only two columns of plates throughout each ambulacral area, all plates are primaries of equal height, pore-pairs uniserial. Interambulacra with four to six columns of plates in each area. The best known species are *Palaeochinus quadriserialis* (Plate 29, fig. 1; Plate 30, figs. 1-7) and *Palaeochinus elegans* (text-fig. 237; Plate 29, figs. 3, 4, 6; Plate 31, figs. 1-5), (p. 304).

The genus *Maccoya* Pomel differs from *Palaeochinus* in that at the mid-zone pore-pairs are biserial. All ambulacral plates extend to the middle of the area, but marginally alternate plates meet the interambulacrum, or are nearly or quite cut off from it by the outer enlargement of their fellows (*M. intermedia*, Plate 34, fig. 2). This makes alternate plates primaries and occluded instead of all primaries as in *Palaeochinus*. In some species the alternate plate may weakly reach the interambulacrum instead of being cut off, *M. sphaerica* (Plate 34, fig. 5). Such make an approach to the character of *Palaeochinus*, but, as the pore-pairs are biserial, it seems best to consider them in this genus. On the interior of the test the plates all cross the half-areas and pore-pairs are uniserial, a radical difference from the exterior of the same structures (Plate 33, figs. 4, 5). The interambulacra have from four to nine columns of plates in each area in the several species. A very perfect periproct is known in *M. sphaerica*. The best known species are *Maccoya burlingtonensis* (Plate 32, figs. 1-3; Plate 33, figs. 1-5), *M. intermedia* (Plate 33, figs. 6-12; Plate 34, figs. 1-3), and *M. sphaerica* (Plate 32, figs. 4, 5; Plate 34, figs. 4-10), (p. 311).

The genus *Lovenechinus* gen. nov. includes species in which at the mid-zone the ambulacrum consists of four columns of plates. In each half-area there is a vertical series of demi-plates which extend from the interambulacrum inward and a similar series of occluded plates that extend from the middle of the ambulacrum outward, but neither series crosses the half-area (Plate 42, fig. 2). Ventrally and dorsally the plates for a brief space are all primaries, and, between these and the character plates, are plates which are alternately primaries and occluded (Plate 42, figs. 1, 3 and 4; text-fig. 237). In this genus there are no isolated plates

such as are present in *Oligoporus* (Plate 50, fig. 7), this being the distinction between the two genera. In the interambulaera of *Lovenechinus* in the known species there are from four to seven columns of plates in an area. Of the several species the most completely known are *Lovenechinus missouriensis* and *L. septies* (Plates 39-45 and 46, fig. 4), (p. 324).

The genus *Oligoporus* Meek and Worthen is characterized by the fact that the ambulaerum at the mid-zone has four columns of plates and, in addition, in the middle line of each half-area isolated plates at intervals, but not in a continuous series so as to make an additional column (Plate 50, fig. 7). This structure is distinctly intermediate between that of *Lovenechinus* and the simplest species of *Melonechinus*. The youthful *Oligoporus* (Plate 50, fig. 8) has exactly the structure of adult *Lovenechinus*, and the youthful *Melonechinus* as a second stage in development (Plate 56, fig. 3) has exactly the structure of adult *Oligoporus*. In the interambulaerum of *Oligoporus* there are from four to nine columns of plates in an area according to the species. All known species are American, from the Lower Carboniferous, and the best known is *Oligoporus danae* (text-fig. 237; Plate 47, fig. 13; Plate 49, figs. 4, 5; Plate 50), (p. 350).

The genus *Melonechinus* Meek and Worthen has many species with a very wide range of characters. The ambulaerum at the mid-zone has from six to twelve somewhat irregular columns of plates. The two median columns of ocluded plates that extend from the middle of the ambulaerum outward are wider than other plates of the area, and are principally involved in the more or less high ridge that usually marks the central line of the ambulaerum. The demi-plates which extend from the interambulacrum inward do not differ externally from others of the area except the ocluded plates, with the exception of the fact that they bevel over the interambulaera. On the outer face of the plates the pore-pairs are surrounded by a peripodium which occupies that part of the plate nearest the next adjacent interambulaerum. On the other hand, on the internal face of the plates the pore-pairs are very near the center of the isolated plates but in demi- and ocluded plates, the pore-pairs lie nearer to the center of the half-area than to the middle of the plates (Plate 56, figs. 4, 5). The ambulacrum of *Melonechinus* on the ventral border has four columns of plates like the typical character at the mid-zone of *Lovenechinus*. Passing from this area dorsally, scattered isolated plates appear, the generic character of *Oligoporus*; further dorsally the isolated plates are more frequent and fall into columns which are more or less in number according to the species in hand. This is shown in text-fig. 245, p. 382; Plate 56, fig. 3; Plate 57, fig. 1; and others. In one area of a specimen of *M. multiporus*, as a regressive variant there are simple primary plates ventrally (Plate 57, fig. 3). This shows that while the genus typically has four columns ventrally, it may revert to two columns as a variation, repeating the character seen at this area in the lower genera of the family, and likewise the character seen at the mid-zone in *Palaeochinus*, the lowest genus of the family. In the dorsal region of *Melonechinus* near the apical disc, in the region of young last added plates, the ambulaerum is also simpler. As few as two plates may

be found next the ocular (Plate 56, fig. 6), and passing ventrally, a progressively increasing number of plates occurs until the full species character is attained. This is shown in outline in text-fig. 237. The interambulaera at or near the mid-zone have from three to eleven columns of plates in each area varying with the species, and somewhat in the species, or indeed in different areas of the same specimen. As in other genera where there is a difference in this respect, the ambulacrum is considered the more essential part and of first consideration in classification; the species are therefore erected first on the basis of specialization of the ambulacrum and secondarily on that of the interambulacrum. Other characters are for the most part essentially similar in all species of the genus. The best known species is *Melonechinus multiporus* (Plate 54, fig. 5; Plate 55; Plate 56, figs. 2-13; Plate 57; text-figs. 237, 245, 246, p. 382; Plate 60, figs. 1, 2), (p. 359).

Having considered briefly the family of the Palaeochinidae, it is seen that the genera, and in addition in *Melonechinus* the species, present a progressive series as regards differential evolution of ambulacral characters; also, where a complex ambulacrum is attained as a character gathered from the mid-zone, the ventral plates built in the youth of the individual are simpler. The young last added dorsal plates as a localized stage in development also present a simpler condition. This relation is expressed diagrammatically in text-fig. 237. This is not a schematic diagram, as each of the several figures is taken directly from the Plates as indicated.

In the figure the species characters are given in the middle horizontal row representing the mid-zone. In the lowest row are given the characters taken at or close to the ventral border of the corona; in the uppermost row are given the characters of plates at or close to the ocular plates. Between the lowest row or the uppermost row and the mid-zone are given the intermediate characters, both ventral and dorsal.

In *Palaeochinus elegans* and other species of the genus the plates are simple primaries throughout the length of the ambulacrum, the simplest condition in the family. The plates are wanting at the ventral border in the known specimens of this species, therefore in the diagram a gap occurs at this point. In *Maccoya burlingtonensis* the plates ventrally are simple primaries, at the mid-zone primaries and occluded plates alternating, and dorsally simple primaries. In *Lovenechinus missouriensis* ventrally the plates are simple primaries, higher up alternately primaries and occluded, and at the mid-zone demi- and occluded plates. Passing dorsally, we find primary and occluded plates alternating, and close to the dorsal border primaries only.

In *Oligoporus danae* again, the plates ventrally are simple primaries, above that alternately primaries and occluded, above that demi- and occluded plates. At the mid-zone there are in addition scattered isolated plates which is the generic feature. Passing dorsally we find demi- and occluded plates only, which doubtless were succeeded near the oculars by primaries only, but such are not preserved in available specimens.

In *Melonechinus* we have the most specialized genus with from six to twelve columns of

ambulaeral plates at the mid-zone. In this genus ventrally there are four plates in each area instead of two as in the preceding genera, although exceptionally in one known case, as a regressive variant, in one area simple primaries occur (Plate 57, fig. 3). In *Melonechinus springeri* ventrally the plates are demi- and ocluded, higher up isolated plates appear; at the mid-zone there are three definite columns in a half-area. Above the mid-zone we pass into an area of demi-, ocluded, and scattered isolated plates, then demi- and ocluded only, and near the ocular primaries only. We see in this and other species of the genus that dorsally a simpler condition exists than that found at the ventral border of the corona, emphasizing the value of localized stages in studies of development.

In *Melonechinus indianensis* ventrally the plates are demi- and ocluded, higher up demi- and ocluded, with scattered isolated plates; higher again three columns, and at the mid-zone four columns of plates in a half-area, the species character. Passing dorsally we find three columns, then two, and near the ocular primaries only. In *Melonechinus multiporus* the same condition occurs, but a little more complex. At the ventral border plates are demi- and ocluded, higher up the same with scattered isolated plates, then three columns, then four, and at the mid-zone five columns in a half-area as the full specific differential. Passing dorsally, we fall into four columns, then three, two, and near the ocular primaries only may occur as in the same area in all lower species and associated genera. The extreme condition of the family occurs in *Melonechinus giganteus*. Here from conditions of preservation certain stages are wanting, but ventrally there are demi- and ocluded plates, next as far as preserved an area with three columns, then one with five, and at the mid-zone there are six columns in the half-area. *Melonechinus keepingi* at the mid-zone has six columns in the half-area as in *giganteus*, and the dorsal area of this species was therefore used to complete the diagram, which I could not do in the case of *giganteus*. Passing dorsally from the mid-zone, we find a condition of five columns, then four, three, two, and finally primary plates only close to the dorsal border of the area.

TEXT-FIG. 237.— Illustrating the structure of the ambulaerum in representatives of the Palaecehinidae as seen at the mid-zone, with the phylogensis of the same as shown by ventral youthful stages and dorsal localized stages of the species shown. Numerals indicate number of columns of ambulaeral plates in a half-area. (Compare text-figs. on pp. 54, 59).

Palaecechinus elegans M'Coy (from Plate 31, fig. 1).

Maccoya burlingtonensis (Meek and Worthen) (from Plate 33, figs. 1, 2).

Lovenechinus missouriensis (Jackson) (from Plate 42, figs. 1-4).

Oligoporus danae Meek and Worthen (from Plate 50, figs. 1, 7, 8).

Melonechinus springeri sp. nov. (from Plate 52, figs. 2, 3).

Melonechinus indianensis (Miller and Gurley) (from Plate 53, figs. 1-3).

Melonechinus multiporus (Norwood and Owen) (from Plate 56, figs. 2, 3, 4, 6; Plate 57, fig. 1, and text-fig. 245, p. 382).

Melonechinus giganteus (Jackson). Of this species the structure from the ventral border to the mid-zone is represented below the black line (from Plate 59, figs. 12, 13, and Plate 61, fig. 8).

Melonechinus keepingi sp. nov. at the mid-zone has the same character as *giganteus*, and its dorsal area is represented above the black line (from Plate 59, fig. 1).

Zone of ocular plates.	<i>Palaeoechinus elegans</i> .	<i>Maccoya burlingtonensis</i> .	<i>Lovenechinus missouriensis</i> .	<i>Oligoporus danac</i> .	<i>Melonechinus springeri</i> .	<i>Melonechinus indianensis</i> .	<i>Melonechinus multiporus</i> .	<i>Melonechinus giganteus</i> below the heavy line, and <i>Melonechinus keepingi</i> above the heavy line.
Dorsal border, localized stages in development.								
Dorsal intermediate zone, localized stages in development.								
Mid-zone, area of full adult characters of the species.								
Ventral intermediate zone, youthful stages in development.								
Ventral border, youthful stages in development.								
Zone of peristome.								

As shown in the diagram by connecting dotted lines, each type in the development of its ambulacrum presents a series of stages, either ventrally as youthful or dorsally as localized stages or both, which are directly comparable to the adult (mid-zone) character of all the simpler preceding types of the family. As the result, a complete genealogical history of the family can be read from the study of the ambulacrum. It is also seen how completely developing plates as localized stages repeat the characters seen as stages in the developing individual gathered from the plates from the ventral border up to the mid-zone. This is comparable to the developing characters occurring in successively added septa in ammonites, as shown by Hyatt and others, where also localized stages occur, as I showed (Jackson, 1899, p. 134).

The family Lepidesthidae is enlarged over what it was when I first published it (1896) to include certain old genera and one new one. It presents a wide range of characters, yet it is difficult with present knowledge to make two distinct families for the included genera. The sum of the characters affiliates the group as an offshoot from the Palaeoechinidae, and the extreme characters seen in several species mark this as one of the most specialized of all groups of Echini. There are from two to twenty columns of plates in each ambulacral area and from three to twelve columns of plates in each interambulacral area. The plates are moderately or more usually strongly imbricate, and bear secondary spines with imperforate tubercles only, or in some genera part or all of the interambulacral plates bear also a primary spine with a perforate tubercle. Where the ventral border of the corona is known, the primordial interambulacral plates are in place, but this area is unknown in some of the genera. In *Lepidechinus* and *Lepidesthes* the peristome is covered with ambulacral plates only, and the same condition probably exists in the other genera. Oculars are all insert or may be exsert. Genitals have from one to many pores each, and the periproct is heavily plated. The lantern has the usual Palaeozoic characters, but in one genus the teeth are distally denticulate. The simplest of the Lepidesthidae are so similar to the simplest members of the Palaeoechinidae that the Lepidesthidae may well have been derived from that stock (p. 393).

The genus *Lepidechinus* Hall makes a close approach to *Palaeoechinus*. It differs from it mainly in that the plates imbricate moderately, and that interambulacral plates bevel over the ambulacrals instead of the ambulacral plates beveling over the interambulacrals, as in *Palaeoechinus* and all of its family. The ambulacral plates are all primaries, nearly uniform in height, or with a slight tendency for alternate plates to become enlarged against the interambulacral suture, pore-pairs are nearly or quite uniserial. Interambulacral plates are in four to eight columns in each area. These plates are rounded hexagonal, with curved surfaces bearing secondary spines and tubercles only. Oculars are all exsert and genitals with a single pore each as far as preserved in *L. tessellatus*, the only species of the genus in which they are known (Plate 63, figs. 7, 8). The species are all known from fairly complete specimens (Plate 62, figs. 1-5; Plate 63; Plate 64, fig. 1), (p. 394).

The characters of the genus *Perischodorus* M'Coy (Plate 62, figs. 6, 7; Plate 64, figs. 2-8) are taken from *P. biserialis* M'Coy, the only satisfactorily known species. The ambulacra have two columns of plates in each area at the mid-zone, they are alternately wedge-shaped, or a plate may be quite shut out from interambulacral contact; pore-pairs are more or less biserial, but dorsally all plates are similar primaries with pore-pairs uniserial. Interambulacra have five columns of rounded strongly imbricate plates in each area; the plates of the adradial columns bear each an eccentric perforate primary tubercle. The primordial interambulacral plates are in the basicoronal row, there being no coronal resorption. Genital plates have numerous pores. This genus has several characters like the *Lepidocentridae*, in which family I previously placed it, but the sum of the evidence seems to place it in this family. One additional species, *P. illinoisensis*, is known incompletely.

The genus *Perischoidaris* Neumayr (Plate 65, figs. 1, 2; Plate 67, figs. 1-3) is known only from one species, *P. harteiana* (Baily). It has a high rounded test with six columns of plates in depressed furrows in each ambulacral area. The interambulacra have five columns of rounded hexagonal plates which indicate moderate imbrication. The actual plates are not preserved as the only known specimens are two external sandstone molds. Part of the adradial interambulacral plates bear an eccentric perforate primary tubercle and all interambulacral plates bear secondary tubercles. Dorsally three of the interambulacral columns drop out, so that in each area only two columns exist next the apical disc, a degree of dropping out seen in no other Palaeozoic species. The ocular plates are all insert and genitals have many pores. The ventral half of the test is unknown.

Proterocidaris Koninck (Plate 65, fig. 3; Plate 67, figs. 4-7) contains only one species, *P. giganteus* Koninck. I have not seen specimens, but observations were made from Fraipont's excellent photographic figures, which he refers to *Oligoporus soreili* Fraipont. It is certainly not *Oligoporus*, and is referable to de Koninck's species. The test is very large, apparently nearly or quite spherical. There are four columns of plates in each ambulacral area and from eleven to thirteen columns of plates in each interambulacral area, varying in areas of the same specimen. This is the only species in the family with many interambulacral columns. The plates are strongly imbricate and bear rather small primary with numerous secondary spines.

Lepidesthes Meek and Worthen, is a most interesting genus; the species are mostly small and elliptical or spherical. The ambulacra are wide and in each area consist of from eight to sixteen columns of very regular rhombic or more or less hexagonal plates, and the interambulacra, which are relatively narrow, of from three to seven columns of plates in each area. Plates are thin, strongly imbricating, bearing secondary spines and tubercles only. The primordial interambulacral plates are in the basicoronal row, and the peristome is covered with ambulacral plates only. Ocular plates are insert, or in one species exsert, and genitals have few pores. The periproct is covered with many moderately thick plates. This is one of the most extreme

genera of Echini for ambulacral differentiation. The best known species are *Lepidesthes formosa* (Plate 66, figs. 4-7; Plate 68, figs. 3-14) and *L. colletti* (text-figs. 14, p. 54; 32-38, p. 75; 251; Plates 69, 70; Plate 71, fig. 1).

Pholidocidaris Meek and Worthen is one of the most specialized in certain respects of Palaeozoic genera. There are from four to six columns of plates in each ambulacral area, but the plates are very large ventrally and small dorsally. A peculiarity is that the pores are situated in the middle of the plates, a primitive character. The interambulacra as far as known have five or six columns of plates in an area and the plates are rounded polygonal. The adambulacral plates dorsally are very much larger than the intermediate plates, one equaling in height the distance of two or three of the adjacent interambulacral plates. This is a character known in no other Echini. In addition the adambulacral plates bear each one eccentric primary spine and perforate tubercle, with secondary tubercles. The intermediate plates dorsally bear secondary tubercles only. The primordial interambulacral plates are in the basicoronal row, and the imbrication of coronal plates is extreme. The genital plates have many pores. No species is known perfectly, but the best known is the genotype, *Pholidocidaris irregularis* (Plate 73, figs. 3-7; Plate 74, figs. 1-7; Plate 75, figs. 1-5).

Meekechinus gen. nov. (Plate 75, figs. 6-8; Plate 76) is in some respects the most specialized of known Echini, and is based on the single species *M. elegans* sp. nov. There are twenty columns of low rhombic plates at the mid-zone in each ambulacral area, the highest number known in any sea-urchin. With this great expanse of ambulacrum there are only three columns of small plates in each interambulacral area. All plates are strongly imbricate, all interambulacral plates bear a small primary spine and tubercle, with secondary tubercles, with the same on the ambulacral plates. Ocular plates are apparently all exsert, and genitals are large, the madreporite being exceptionally large and with distinct madreporic pores, the clearest seen in any Palaeozoic species. Pedicellariae were found in this remarkable species, and are the only ones yet known from the Palaeozoic. The lantern has the typical Palaeozoic characters except that the teeth are distally denticulate, a unique character for Echini. This species is the highest geologically and the most specialized structurally of any known Palaeozoic echinoid.

If this classification is adopted the names Palaeochinoida and Euechinoida will naturally lapse as the major divisions of the Echini are ordinal only as shown in the table, p. 209.

PART III.

PALAEOZOIC ECHINI.

In considering the systematic part of this memoir, attention is called to the general statements of the history of the subject, sources of material, methods of work, etc., as given in the Preface and Introduction. The morphological part of this memoir is based in considerable part on the study of Palaeozoic species, so that considerations of these older forms and their relations are scattered all through the morphological sections. As references to the pages of these earlier considerations of Palaeozoic genera and species can be gathered from the index they are largely omitted in the descriptions.

A key to the classification of Palaeozoic Echini is given in the last section (p. 201-208), and a systematic table (p. 209), showing the genealogical relations, as understood, of the Palaeozoic Echini to each other and to the larger groups of the post-Palaeozoic Echini. An asterisk before the name of a species indicates that specimens have been studied. Under each species the synonymy is given in full as far as ascertained, and references to the principal literature. Miss Klem (1904) has recently published so full a list of references in her Revision of Palaeozoic species, that it seems unnecessary to repeat minor references. All text-books are omitted unless there is special need of comment, also works in which species are simply listed without description or discussion, as Miller's Catalogue of North American Geology and Palaeontology, Etheridge's and Morris's Catalogues of British Fossils, d'Orbigny's Prodrôme, Dujardin and Hupé's Echinodermes, etc. Where species are simply listed without description or discussion, as in parts of Lovén's (1874) and Miss Klem's (1904) memoirs, no reference is deemed necessary. Messrs. Lambert and Thiéry's *Essai de Nomenclature* (1910) has recently come to hand (March, 1911). Their distribution of Palaeozoic species in genera and their generic synonyms do not appear to me well considered. While there are no descriptions of species in Lambert and Thiéry's *Essai*, names from this work are included as a matter of synonymy. In my descriptions of species I have given what are considered the essential features with new matter. Where further information is desired, it may be obtained from the authors cited.

GEOLOGICAL DISTRIBUTION.

Considering in brief and in a broadly inclusive way the geological distribution of Palaeozoic Echini, their occurrence in formations is as follows. In the Ordovician, Echini are known only from Russia where the primitive genus *Bothriocidaris* is represented by three species.

In the Silurian, Echini are represented thus far only in America and England. In the Niagara Group of New York State is found the oldest known representative of the Lepidocentridae, *Koninckocidaris silurica* sp. nov. The position of the Niagara is about in the middle of the Silurian. In England, *Maccoya phillipsiae* (Forbes) is ascribed to the Llandovery which is at the base of the Silurian, but this horizon for the species may be doubted. In the British Museum there is an excellent echinoid lantern from the Wenlock Limestone of Dudley,¹ the oldest assured horizon from which an echinoid is known in Great Britain. In the Lower Ludlow, which is the upper part of the Silurian, just below the Devonian, occur in England *Palaeodiscus ferox* Salter, and *Echinocystites pomum* Wyville Thomson, the sole representatives of the order Echinocystoida.

In the Devonian, as in the Silurian, only a few Echini are known. In the Devonian of Germany *Eocidaris laevispina* (Sandberger) is fragmentarily known. This is the only species here ascribed to that genus and it is the earliest, also the only known representative of the Archaeocidaridae in the Devonian. In the Devonian of Germany also are found *Lepidocentrus rhenanus* (Beyrich), *L. mülleri* Schultze, and *L. eifelianus* Müller. *Lepidocentrus drydenensis* is found in the Upper Devonian of America, in New York State. All species of *Lepidocentrus* are Devonian excepting one, which is found in the base of the American Lower Carboniferous. In England *Lepidesthes devonians* Whidborne and *Pholidocidaris acuaria* (Whidborne) occur in the Devonian; they are the oldest representatives of their genera and of the family Lepidesthidae. The imperfectly known *Xenocidaris*, with three species, is found in the Devonian of Germany.

The term Subcarboniferous is commonly used in America for the lower part of the Carboniferous, below the Coal Measures. I use here the term Lower Carboniferous. This is a more nearly correct name for the horizon and has the advantage of coinciding with foreign usage. The Lower Carboniferous is the period of greatest development of Palaeozoic Echini and it is in America that the most species are found. Here occurs the *Miocidaris cannoni* sp. nov. which is important as the geologically oldest known member of the Cidaridae, which family is a salient feature of the Echinoid fauna from Mesozoic to Recent times. The genus *Archaeocidaris* also first appears in the Lower Carboniferous, and in this formation there are many species in both America and Europe.² The genus *Lepidocidaris*, structurally the highest member of the Archaeocidaridae,

¹ This lantern, which was recently discovered in the matrix and developed by Dr. Bather, is well preserved. It has wide-angled pyramids, a moderately deep foramen magnum, and a brace in place. The sides of the pyramids have ridges for the attachment of interpyramidal museles. It has the essential characters of lanterns, as seen in the Lower Carboniferous. As there is no portion of the test in association with the lantern, its generic position is unknown, but it is quite probable that it is a *Lepidocentrus* or a near ally of that genus.

² Dr. Bather called my attention to the fact that Austin (1848) reported that a large species of *Echinoerinus* [*Archaeocidaris*] occurs in the Wenlock Limestone, Silurian, of Glidden Hill, which is near Coalbrookdale in Shropshire. There is no recognizable description, and the specimen is unknown. If this observation should be confirmed, it would greatly extend the geological range of the genus.

is known from one species in the American Lower Carboniferous. The Lepidocentridae is represented in America by *Lepidocentrus whitfieldi* sp. nov., also *Hyaltechinus rarispinus* (Hall), *H. pentagonus* sp. nov., and *H. beecheri* sp. nov., all from the Waverly Group, the basal member of the Lower Carboniferous. The Lepidocentridae also is represented in America by *Pholid-echinus brauni* gen. et sp. nov., from the Keokuk zone, and in Europe by *Koninckocidaris cotteau* Dollo and Buisseret, from Belgium, and *Tornquistellus gracilis* (Tornquist) from Germany. Of the Palaeochinidae, *Maccoya phillipsiae* is attributed to the Silurian of England, but with this exception the family of the Palaeochinidae is known only from the Lower Carboniferous of America and Europe. Of this family the genera Palaeochinus, Maccoya and Lovenechinus are represented by both American and European species, but Oligoporus, is American only. Of the highest genus of the family, Melonechinus, eleven species are American, two are British, and one Russian. Of the Lepidesthidae, most of the species are from the Lower Carboniferous, but two are found in the Devonian as above noted, and two occur in later horizons. Lepidechinus, the lowest genus of the family, is known wholly from the Lower Carboniferous, three species, *L. iowensis* sp. nov., *L. tessellatus* sp. nov., and *L. imbricatus* Hall, being found in America, and one species, *L. irregularis* (Keeping), in Ireland and France. Perischodomus is represented by one well known species, *P. biserialis* M'Coy, in the Lower Carboniferous of Ireland and England, and one imperfectly known species in America. Perischocidaris is known only from *P. harteiana* (Baily) in the Lower Carboniferous of Ireland. Proterocidaris is known from the striking species, *P. giganteus* Koninck, from the Lower Carboniferous of Belgium. The relatively large genus Lepidesthes has one species in the British Devonian and one in the American Coal Measures, but all others are from the Lower Carboniferous. Of these, six species are American, one British, and one Russian. As above stated, one species of Pholidocidaris is from the Devonian, but the others known are from the Lower Carboniferous. One species, *P. irregularis* Meek and Worthen, the best known is American. *P. tenuis* Tornquist is known in England and Germany and *P. gaudryi* Julien in France.

In the Upper Carboniferous, or Coal Measures, the Palaeozoic Echini have dropped out with extreme suddenness and relatively few species are known. The genus Archaeocidaris is represented by 19 species recorded from the Coal Measures, all known fragmentarily only from spines and plates. Seventeen of these have been recorded from America and two from Europe.¹ Besides Archaeocidaris in the Coal Measures of America is found *Lepidesthes extremis* sp. nov., structurally and geologically the highest known species of this very interesting genus.

¹ The following species of Archaeocidaris have been found in the Coal Measures of North America as recorded by various authors: *A. longispina* Newberry, *A. agassizi* Hall, *A. coloradensis* nom. nov., *A. gracilis* Newberry, *A. aculeata* Shumard and Swallow, *A. edgarensis* Worthen and Miller, *A. tridifer* White, *A. dininnii* White, *A. cratis* White, *A. biangulata* Shumard and Swallow, *A. ourayensis* Girty, *A. triplex* White, *A. megastyla* Shumard and Swallow, *A. triserrata* Meek, *A. halliana* (Geinitz), *A. spinoclavata* Worthen and Miller, *A. sp. b.* Girty. From Europe there are only two species recorded: *A. paraulora* (Eichwald) in Russia, and specimens which are here referred to *A. acanthifera* Trautschold in England.

In the Permian, very few forms of Echini are known. In England and Germany *Miocidaris keyserlingi* (Geinitz) occurs, and is important as the geologically second species known in the Palaeozoic with two columns of plates in an interambulacral area. As far as at present definitely known, it and the new *Miocidaris cannoni* from the American Lower Carboniferous are the geologically oldest members of the Cidaroida. In America, *Archaeocidaris aculeata* Shumard and Swallow is reported as occurring in the Permian, and in India *Archaeocidaris* is doubtfully represented by one species, *A. forbesiana* (Koninck), which is imperfectly known, but is provisionally referred to this genus. *Archaeocidaris selwyni* occurs in the Permian of Australia. In the American Permian is found *Meekechinus elegans* gen. et sp. nov., which is a very interesting type, as it has twenty columns of ambulacral plates in an area at the mid-zone, being in this respect the most specialized of known Echini. It is the highest of the Lepidesthidae and geologically the last of the series with more than two columns of ambulacral and interambulacral plates in an area which is the essential feature of most Palaeozoic Echini.

SYSTEMATIC DESCRIPTIONS.

Order BOTHRIOCIDAROIDA Jackson.

— Schmidt, 1874, p. 37.

Bothriocidaridae Zittel, 1879, p. 480

Bothriocidaroida Jackson, 1896, p. 238.

Regular Echini, with periproct enclosed by the oculo-genital ring. Two columns of plates in each ambulacral area and one column of plates in each interambulacral area.

Family BOTHRIOCIDARIDAE Klem.

Bothriocidaridae (as an order) Zittel, 1879, p. 480; (as a family) Klem, 1904, p. 14.

With characters of the order.

BOTHRIOCIDARIS Eichwald.

Bothriocidaris Eichwald, 1860, p. 654.

Botriocidaris Neumayr, 1881, p. 4.

Botryocidaris Lovén, 1883, p. 57.

Small spherical or elliptical Echini. Ambulacral areas relatively wide, about twice as wide as the narrow interambulacra with their single columns of plates. Ambulacral plates high, hexagonal, the pores of each pore-pair superposed in a depression in the center of each plate. Interambulacral plates high, hexagonal, equaling the ambulacrals in height. Plates

of test not imbricate. Primordial interambulacral plates are in the basicoronal row. Basicoronal ambulacral plates are not sharply distinguished from the peristomal plates. Spines few on ambulacral and interambulacral, or on ambulacral plates only. Peristome with two rows of ambulacral plates only. Oculars very large, genitals small. Periproct with many small, angular plates, filling the area. Ordovician, Russia. This is the oldest known genus of Echini and also one of exceptional interest on account of its features which in many respects resemble the young of later Echini. The type species is *Bothriocidaris globulus* Eichwald, from the Ordovician of Russia. (See pp. 54, 64, 70, 80, 87, 149, 208.)

Key to the Species of Bothriocidaris.

Oculars continuous, forming a closed ring; small genitals dorsal to the oculars; tubercles on ambulacral and interambulacral plates, *B. archaica* sp. nov., p. 239.

Oculars in part continuous and in part separated by the small genitals; tubercles on ambulacral plates only, *B. pahleni* Schmidt, p. 242.

Oculars all separated by the small genitals; tubercles on ambulacral and interambulacral plates, *B. globulus* Eichwald, p. 243.

***Bothriocidaris archaica** sp. nov.

Text-figs. 2, p. 54; 22, p. 70; 40, p. 80; 162, p. 149; Plate 1, figs. 1, 2.

Bothriocidaris globulus (pars) Jaekel, 1894, text-figs. 1, 2: (pars) A. Agassiz, 1904, p. 79; (pars) Klem, 1904, p. 15.

Bothriocidaris [globulus pars] Bather, 1902, p. 620, text-fig. 5B.

* The precious and only known specimen of this species is in the Museum für Naturkunde in Berlin, and I am under greatest obligations to Dr. Otto Jaekel for the opportunity to study this which, I feel, is perhaps the most interesting of known Echini. The details of structure are remarkably clearly preserved, but are naturally difficult to study in such a small specimen. It is probably the best preserved specimen known in the genus, and is marvellously perfect when its age is considered. Its perfection is a tribute to Dr. Jaekel's skill as a preparator.

The test is slightly elliptical, 12 mm. in height, 11.2 mm. in diameter through the mid-zone. The circumference at the ambitus is 35.5 mm.; circumference in a vertical plane around the poles 36 mm., width of an ambulacrum at the mid-zone 4.2 mm., width of an interambulacrum at the same area 2.2 mm. Each ambulacrum consists of two columns of high hexagonal plates; at the mid-zone a plate measures 2.2 mm. in its greatest width. Ambulacral pores are superposed in a sunken area in the center of each plate. At the ambitus there are typically four, in some cases perhaps fewer, tubercles on each plate near the margin of the peripodium. Interambulacral plates are high, hexagonal, equaling the height of the ambulacrals, with from one to three tubercles on each plate at the mid-zone. The plates of the corona are not imbricate. There are two rows of peristomal ambulacral plates. The diameter of the apical

disc through the plane III, 5 is 4 mm. This measurement includes from the adoral border of ocular III to the aboral tip of the youngest plate of interambulacrum 5. The apical disc measures proportionately 36% of the diameter of the test. This proportion is about the same as in the modern Cidaridae and is relatively larger than in other known Palaeozoic species (pp. 87, 104). Oculars are large, forming a closed ring, thus covering the ambulacra and inter-ambulacra completely, a unique character. Genitals are small and shut out from contact with the interambulacra by the continuous character of the oculars (p. 87). The periproct has many small angular plates filling the area.

This species differs from *B. pahleni* in that there are perforate tubercles on both ambulacral and interambulacral plates, whereas in *pahleni* they are absent in the interambulacrals. It also differs in that the genitals are wholly dorsal to the oculars instead of part of them separating the oculars as in *pahleni*. *Bothriocidaris archaica* differs from *globulus* in that the oculars form a closed ring, whereas in *globulus* the oculars are separated by the genitals which meet the interambulacra of their several areas.

Lyckholm Schicht, Ordovician, Hohenholm, Island of Dago, Russia. The type and only known specimen is in the Berlin Museum as above stated.

In the morphological part of this memoir much attention is given to *Bothriocidaris* as a primitive type, and the consideration is largely based on the study of this species. The ambulacrum is a feature of particular interest. The whole of ambulacrum IV measured on the curve from the oral termination to the ocular is 15 mm. in length. The two ventral rows of ambulacral plates are considered as peristomal, from which the basicoronal plates of the corona are not sharply defined. In the corona proper, and excluding the peristome, there are eight ambulacral plates in each column of each area excepting IIIa, in which there are nine plates, as a very young plate is in contact with the ocular, but so low that it does not quite reach the interambulacrum. Pore-pairs are superposed in the middle of each plate, a condition known in the adult of regular Echini only in this genus (text-fig. 22, p. 70). At the mid-zone there are four perforate tubercles to a plate, or in some plates fewer; when fewer at this area, the difference may be due to loss from erosion. Ventrally and dorsally there are fewer tubercles as a character. In the sixth plate from the base in ambulacrum IIa, the tubercles were not seen, but are filled in by comparison with adjacent plates, otherwise the tubercles of ambulacral plates are figured as observed. The hexagonal shape and superposed pores are like the young of later Echini (pp. 54, 57).

Interambulacrum 3 measures on the curve 12 mm. in length. In each interambulacrum there are nine plates, and the basicoronal plate of each area is a pentagon, the ventral apex of which impinges on the second row of peristomal ambulacral plates (compare Plate 2, fig. 1; Plate 3, figs. 9, 10). The tubercles of these plates are few in number, but striking. There is a single tubercle on the basicoronal plate in each area, also a single tubercle on the second

plate in each area excepting 2, where it is wanting, doubtless from erosion; in the third and succeeding plates to the mid-zone there may be one, two, or three tubercles varying with the areas, the highest number occurring in area 4. Dorsally, for one or more plates in an area, there is only one central tubercle to a plate like that in the basicoronal plates. In the youngest interambulacral plates in contact with the oculars, there are no tubercles, a common character of plates next the apical disc. The characters of the tubercles on the interambulacra express radial variation, ventral development, and dorsal localized stages. The distribution of tubercles on interambulacral plates is striking from the difference in different areas. Of course some tubercles may have been worn off, but those shown are probably essentially the number that existed when the animal was alive. Dorsally (Plate 1, fig. 2) the interambulacra abut against two oculars, a condition otherwise known only in spatangoids (text-fig. 175, p. 149), and in aberrant variants of regular Echini (Arbacia, Plate 4, figs. 11, 12; Eucidaris, text-fig. 185, p. 167). The single column of interambulacral plates is considered a primitive character, because in the young of all later Echini there is a single plate in the basicoronal row representing a single column as a stage in development (compare text-figs. 22-31, p. 70). There is no resorption of the base of the corona, a character of the young in all later Echini and of certain adult types of later Echini (p. 70).

The peristome of this ancient type (Plate 1, fig. 1; text-fig. 40, p. 80) consists of two rows of ambulacral plates. The first row represents the primordial ambulacral plates, and examining them, we find that the Ia, IIa, IIIb, IVa, Vb are larger plates, and the Ib, IIb, IIIa, IVb, Va are smaller. This is in accordance with the law worked out by Lovén in Recent Echini (Plate 2, fig. 1), and it is most striking that it was already at work in these ancient times. By means of it I oriented the specimen as shown in the figures. I could distinguish no tubercles on this first row of plates. The second row of the peristome surrounds the first and aborally is in contact with the basicoronal interambulacral and ambulacral plates. The plates of this second row are distinguished from the coronal plates only by their position and interambulacral relation,¹ but the same thing is true of the young of some Recent types (Plate 2, fig. 6). The second row was probably derived by flowing down from the corona (pp. 79, 86). On some plates of this second row one or two tubercles were observed.

The oculars are very large relatively, and are unique in that they meet in a continuous ring. Ocular III measures 1.4 mm. in height, but the others somewhat less. All have three tubercles excepting II, which has only two. Ocular III has in addition two tiny sinuous elevations which appear to be part of the plate. Jaekel thought these indicated a madreporite; this may be correct, but it is doubtful. The small plates in the dorsal interradial angles of the oculars I consider as genitals (as discussed, p. 88). Genitals 1, 2 and 4, 3 are in contact

¹ By an error in making my drawing in Berlin, from which original Mr. Blake drew Plate 1, fig. 1, the initial plate of area 1 rests against the third plate of Ib, instead of the second plate as it evidently should.

dorsally, as seen in Plate 1, fig. 2, but a periproctal plate separates genitals 2 and 3 and others separate genital 5 from 4 and 1 on either side. They thus present a certain bilateral symmetry, but this may be only a coincidence. All the genitals bear a tubercle excepting genital 2, where it is probably worn off, but if madreporic pores existed in 2, that might account for the absence of a tubercle. The small relative size of the genitals and their position dorsal to the oculars suggests a comparison with the somewhat similar condition in embryonic *Echinus* as seen in Plate 3, fig. 5.

The periproct contains nine or ten minute angular plates, the sutures of which are difficult to make out, but apparently are as shown in the figure. They are similar to plates seen in other Palaeozoic periprocts and present no striking feature (p. 174).

Teeth, or more probably, dental pyramids exist in areas I, II, IV, and V. Jaekel considered them parts of the dental system, and I agree with him, but Bather differs because of their radial position. No other known structure occurs at this area in *Echini*, and their position, it seems, may be accounted for by a possible accidental twist, as a considerable twist is occasionally found in dried Recent material. To accept a radial position as normal in this type is opposed to morphological principles, and in so far I should entirely support Bather's opinion.

***Bothriocidaris pahleni* Schmidt.**

Plate 1, figs. 3-6; Plate 8, fig. 1.

Bothriocidaris pahleni Schmidt, 1874, p. 38, Plate 4, figs. 1a-1g; Zittel, 1879, p. 481, text-figs. 339a-339c;

A. Agassiz, 1892, p. 72, Plate 29, fig. 1; Jaekel, 1894, p. 246; Jackson, 1896, pp. 233, 238, text-fig. 4;

Gregory, 1900, p. 300, text-figs. 1-3; Lambert and Thiéry, 1910, p. 118.

Botriocidaris pahleni Neumayr, 1881, p. 152, Plate 1, fig. 6.

Botryocidaris pahleni Lovén, 1883, p. 57, 2 text-figs.

Bothriocidaris pahleni Pomel, 1883, p. 117.

Bothriocidaris phaleni Klem, 1904, p. 15.

The test is small and nearly spherical; according to Schmidt, the type is 15.5 mm. in height and 16 mm. in diameter. Ambulacral plates are high, hexagonal. Schmidt says there are ten plates in a column, and eliminating the two peristomal rows, we have, therefore, eight ambulacral plates in a column in the corona, as in *B. archaica*. The individual ambulacral plates at the ambitus are 3 mm. wide and 2 mm. high. The pits for pore-pairs are about 0.5 to 0.75 mm. broad, showing two pores which are superposed. There are two tubercles to a plate, and some of the spines are in place. They are longitudinally striate, up to 4 mm. long and about 0.5 mm. thick; these are the only spines known in the genus. The interambulacral plates are of the same height as the ambulacral, but narrower, 2.5 mm. wide at the ambitus. The primordial interambulacral plates are pentagonal, ventrally in contact with the dorsal border of the second row of peristomal ambulacral plates. The youngest plates dorsally against the apical disc are pentagonal, or so low that they are nearly triangular. There are eight or

nine plates in a column according to Schmidt, and nine as seen in Plate 8, fig. 1. The surface of these plates is finely granulated, but with no perforate tubercles, indicating that in this species there were no large spines, possibly no interambulacral spines at all. If the latter, it is a unique condition in Echini. There are two rows of peristomal ambulacral plates, the second being in contact with the ventral border of the primordial interambulacral plates. The oculars are large, of which the ocular considered III is the largest. Each plate bears two or three tubercles. Oculars IV, V and I, II are in contact (Plate 1, fig. 6), but IV, III and II, III are separated so that genitals 2, 3 reach the interambulacra. Thus it is structurally bilaterally symmetrical through the axis III, 5, but this may be a mere coincidence. Four small genitals are in place, but genital 5 is wanting; 2 and 3 reach the interambulacra as in *B. globulus*, but the others are shut out by the contact of the oculars. Each genital bears a small perforate tubercle. Considering these plates as genitals, there are three other plates within the apical disc that may be considered as plates of the periproct. This species differs from the other two in that there are no perforate tubercles on the interambulacral plates, and it is intermediate between *B. archaica* and *B. globulus* in the lateral contact of the ocular plates (p. 87).

The type is from the Jeweschen Schicht, Ordovician, Nommis, Esthland; a second specimen, the original of Plate 8, fig. 1, is from the Diluvial-Geschichte, Ordovician, Rostov, Russia.

Lovén (1883, p. 57) described and figured in this species, presumably the type specimen, long cylindrical bodies having one end in close relation to the ambulacral pores. He took these for tube-feet, and said that they even showed traces of having their tubes strengthened by arcuate spicules. It certainly is a remarkable condition of fossilization if these are tube-feet.

In the figure which I published (1896, text-fig. 4, p. 234) of this species, the error was made of taking the perforation of tubercles for ambulacral pores, so that these were represented incorrectly, in a horizontal plane instead of superposed. The same mistake was made by Gregory (1900). The photographic figure (Plate 8, fig. 1) is taken from a cast that was made by Dr. Jaekel and which he kindly gave me. It shows enlarged the general appearance of the species, relative width of plates, and the whole length of one interambulacrum. The interambulacral areas are colored to differentiate them.

***Bothriocidaris globulus* Eichwald.**

Plate 1, figs. 7-9.

— Aldrovandus, 1618, p. 136, fig. 5.

Bothriocidaris globulus Eichwald, 1860, p. 55, Plate 32, figs. 22a, b, but not fig. 23; Schmidt, 1874, p. 40,

Plate 4, figs. 2a-2c; (pars) Jaekel, 1894; (pars) Jackson, 1896, p. 238; (pars) Klem, 1904, p. 15;

(pars) A. Agassiz, 1904, p. 79; Lambert and Thiéry, 1910, p. 118.

Bothriocidaris globulus Neumayr, 1881, p. 152.

Eichwald's original figures and description are not very detailed, but Schmidt gives an excellent description and figures of this species, from which my account is taken. Test globular,

in Schmidt's specimen 18 mm. high, 18.5 mm. in diameter. Eichwald's type was smaller, only 12.5 mm. in diameter. There are two columns of high hexagonal plates in each ambulacral area, and the plates at the ambitus are 4 mm. wide and 3 mm. high. Interambulacral plates are somewhat narrower, 3 mm. wide. Schmidt says that there are ten ambulacral plates in each column, which, subtracting two for the peristomal rows, leaves eight in a column for the corona, as in the two other species. The pore-pairs are superposed in the middle of each plate, and at the ambitus there are four perforate tubercles around the peripodia. The interambulacral plates at the ambitus have two or three perforate tubercles, but ventrally and dorsally only one. Schmidt says that the spines attributed to this species by Eichwald have nothing to do with it, but appear to be small Bryozoa. The peristome consists of two rows of ambulacral plates as in the other species; the dorsal border of the second row is in contact with the ventral border of the primordial interambulacral plates. The oculars are large, the largest of which I take to be III, as in *B. archaica*. They bear one, two, or five tubercles each, but ocular IV has no tubercle, probably worn off. Four genital plates are in place, but genital 4 is absent or displaced (Plate 1, fig. 9). The genitals are larger than in the other species; each bears a tubercle and separates the oculars, therefore reaching the interambulacra as they do in all later Echini, but in this feature differing entirely from *archaica* and partially from *pahleni* (p. 240). There are only two periproctal plates in place lying dorsal to oculars II and III and separating the associated genitals. Schmidt figures five minute plates ventral to the primordial ambulacral plates, and which I take to be teeth or dental pyramids, as in the other species (discussion, pp. 181, 242).

Schmidt's specimen is from the Lyckholm Schicht, Ordovician, Hohenholm, Island of Dago, Russia. The type is from the same locality.

It is very interesting historically that Aldrovandus in 1618 gave a figure that is recognizable as belonging to *Bothriocidaris* and probably to this species. The figure is entitled "Echinus lapis spoliatus a spinis," but there is no description. While somewhat rough, the figure shows two columns of high hexagonal ambulacral plates, with a cup-shaped depression in the center of each, and a single column of high hexagonal interambulacral plates which apparently meets the genitals. There are from one to three tubercles on the interambulacral plates; these features apply to this species and no other. It is remarkable that this excessively rare echinoid should have been found so early and then lost sight of until recent years.

Order CIDAROIDA Duncan.

Cidaroida Duncan, 1889a.

Regular Echini with periproct enclosed by oculo-genital ring. Two columns of low, narrow ambulacral plates and two columns of pentagonal interambulacral plates, the latter with a large, central primary tubercle and spine, also marginal secondary tubercles and spines. Other

characters are of importance if the whole order is to be considered (see pp. 201, 211) but for the Palaeozoic, this is a sufficient diagnosis. It is quite possible that the Devonian genus *Xenocidaris*, with three species, considered under *Incertae Sedis*, belongs to the *Cidaroida*.

Family Cidaridae Gray.

Cidaridae Gray, 1825, p. 4.

With characters of the order.

Miocidaris Döderlein.

Miocidaris Döderlein, 1887, p. 40; Bather, 1909, p. 61; 1909a, pp. 83, 251.

Eotiaris Lambert, 1899, p. 82; Lambert and Thiéry, 1910, p. 127.

Permocidaris (pars) Lambert, 1899a, p. 39.

Eocidaris (pars) Lambert and Thiéry, 1910, p. 126.

Test of moderate size, adradial margin of the interambulacral plates beveled over the ambulacra, interambulacral plates relatively few, or many in *M. cannoni*, often wide, with scrobicules which are circular or elliptical, distinct or confluent. This genus contains but two Palaeozoic representatives, the other species being Triassic or Jurassic. The type-species as selected by Bather (1909, p. 61) is the Triassic *Miocidaris cassidina* Bather (a new name for *Cidaris* (*Miocidaris*) *klipsteini* Desor, which was preoccupied). Dr. Bather (1909; 1909a, pp. 83, 251) has given a critical consideration to this genus and to the species attributed to it. The genus *Miocidaris* is of especial interest as it contains the geologically oldest known forms of the Cidaridae, and at the same time the oldest known Echini with two columns of plates in each interambulacrum, which is the feature of all modern Echini. *Miocidaris keyserlingi* under various generic names has long been known from the Permian of Europe. I have the satisfaction of describing a new species, *M. cannoni*, from the Lower Carboniferous of America, which greatly extends the geological and geographical range of the genus and family.

Key to the Palaeozoic Species of *Miocidaris*.

Test small, about six plates in an interambulacral column *M. keyserlingi* (Geinitz), p. 245.

Test large, about fourteen plates in an interambulacral column *M. cannoni* sp. nov., p. 247.

- ****Miocidaris keyserlingi*** (Geinitz).

Text-figs. 238, 238 bis; Plate 9, figs. 1-5.

Cidaris keyserlingi Geinitz, 1848, p. 16, Plate 7, figs. 1a, 1b, 2a, 2b.

Cidaris verneuilliana King, 1848, pp. 6, 7.

Archacocidaris verneuilliana King, 1850, p. 53, Plate 6, figs. 22-24.

Palacchinus verneuilliana King, 1850, description of Plate 6, figs. 22-24.

Eocidaris kaiserlingii Desor, 1858, p. 156, Plate 21, figs. 15, 16.

Eocidaris verneuilliana Desor, 1858, p. 156, Plate 21, figs. 13, 14; Lovén, 1874, p. 43.

Eocidaris keyserlingi Geinitz, 1861, p. 108, Plate 20, figs. 5-9; Lovén, 1874, p. 42; Klem, 1904, p. 68.

Eocidaris kaiserlingi Kolesch, 1887, Plate 38, figs. 1-27; Döderlein, 1887, p. 39, Plate 11, fig. 8; Spandel, 1898, p. 33, Plate 13, figs. 1-6.

Eotiaris keyserlingi Lambert, 1899, p. 82; Lambert and Thiéry, 1910, p. 128.

Permocidaris verneuilli Lambert, 1899a, pp. 39, 47.

Eocidaris verneuillanus Klem, 1904, p. 70.

Miocidaris keyserlingi Bather, 1909, p. 54, text-figs. 2, 3, Plate 1, figs. 6-17; 1909a, p. 86.

Eocidaris verneuilli Lambert and Thiéry, 1910, p. 126.

This important species has recently received critical consideration from Dr. Bather. The test is small, low, subspheroidal. Ambulacra unknown, but crenulations on the adradial suture face of the interambulacral plates indicate that about four ambulacral plates equal the height of an interambulacral (text-fig. 238 *bis*). Two columns of relatively high pentagonal plates in each interambulacral area, beveled over the ambulacrals on the adradial suture. The tubercles are prominent, crenulate, with large scrobicules and numerous secondary tubercles on the extra-scrobicular surface. Bather shows that there are low but clearly developed

238

238 bis

TEXT-FIGS. 238, 238 *bis*.—*Miocidaris keyserlingi* (Geinitz). Magnesian Limestone, Permian, Tunstall Hill, County Durham, England.

238. One of the most perfectly preserved specimens of an interambulacrum, showing the association and general shape of the plates. The scrobicules are confluent. $\times 6$. (After Bather, 1909, text-fig. 2, p. 58.)

238 *bis*. Greater part of an interambulacrum, interior view, showing beveled sutures, denticulation of adambulacral margin and apophyses of perignathic girdle. (After Bather, 1909, Plate 1, fig. 9.)

apophyses on the basicoronal plates, as seen from the interior of the test (text-fig. 238 *bis*). These are the only such structures known in the Palaeozoic (p. 190). The fragment of a test in the Dresden Museum (Plate 9, fig. 2), which is one of Geinitz's original specimens, consists of six plates and measures 5.3 mm. in width.

The primary spines are up to about 8 mm. in length, above the lower part with small

spinules directed distally. Bather gives much detail in regard to the structure of this species, and says there is no good ground for separating *verneuilliana* and *keyserlingi* specifically.

Lower Zechstein, Permian, Corbusen, Ronneburg, Germany, cotypes, Dresden Museum; near Posneck, Thuringia, Museum of Comparative Zoölogy 3,193; Permian, Zechstein, Freiburg i. B. Museum; Permian, Humbleton Hill and Tunstall Hill, British Museum.

* *Miocidaris cannoni* sp. nov.

Text-figs. 239a—239e

This species is represented by a single specimen kindly sent to me by Mr. George L. Cannon, instructor in geology and biology in the Denver High School, of Denver, Colorado. It was received too late (August, 1911) to be figured otherwise than by insert cuts, which with the description are inserted in proof-sheets.

TEXT-FIGS. 239a—239e.—*Miocidaris cannoni* sp. nov. Millsap Formation, Lower Carboniferous, near Denver, Colorado. Holotype. Museum of Comparative Zoölogy Collection 3,201.

a. View of the specimen. $\times 2$. A few interambulacral plates are in place in interambulacra A, C, and E. The rest of the specimen consists of an internal siliceous mold.

b. Outline of an internal impression of an interambulacral plate from area C. $\times 4$. Showing elevated mamelon.

c. View across the dorsal part of interambulacrum C. $\times 4$. Showing fragments of three plates in place which meet the median suture; the outlines of the plates are restored, as indicated by dotted lines.

d. Interambulacral plate from near the mid-zone in area E, with about four opposing ambulacral plates, which are indicated by siliceous casts of the pore-pairs. $\times 4$.

e. Section of an interambulacral plate in the dorsal part of area E, showing its beveled edge on the adradial suture. $\times 4$. The outline of the ambulacrum is seen in section and siliceous molds of the pore-pairs exist as elevated plugs.

The specimen is a siliceous internal mold and about half of it is embedded in a hard siliceous chert. A few fragmentary worn interambulacral plates are preserved. The specimen shows two ambulacral areas, one interambulacrum complete from the ventral border to the apex, and parts of two next adjacent interambulacra. The impressions of sutures on the mold are clear only in parts, but they are perfectly clear in the plates, as far as these are preserved.

The test is depressed spheroidal, free from all distortion, and measures about 20 mm. in

height by 29 mm. in diameter. No ambulacral plates are preserved, so that the characters of the ambulacra are derived wholly from the mold. The ambulacra at the mid-zone measure about 7.5 mm. in width. As this is a measurement of the interior, on the exterior the width would be somewhat less, because the interambulacral plates bevel over the ambulacrals on the adradial sutures (text-fig. 239e). There are two columns of low plates in each ambulacrum. The position of the plates is indicated in part by rather obscure impressions of sutures, but mainly by the siliceous plugs which represent the casts of pores of the pore-pairs (text-fig. 239c). The pores of each pore-pair at the mid-zone are 1 mm. apart, and the distance from the outer pore of one plate in a right half-area to the outer pore of the adjacent plate in a left half-area is 6 mm. Four ambulacral plates equal the height of an interambulacral plate at the mid-zone, as gathered from the number of pore-pairs in the mold opposed to an interambulacral plate which is in place (text-fig. 239d). This number is similar to the number of ambulacral plates opposed to an interambulacral in *Miocidaris keyserlingi*, as stated above, but it is much smaller than the usual number in the adults of Recent cidarids (compare text-fig. 218, p. 191). In the young of Recent cidarids, however, the ambulacral plates are higher and in very young specimens may be even as high as the interambulacrals (Plate 2, fig. 2).

The only interambulacrum which is entirely exposed to view measures 12 mm. in width at the mid-zone. In the same plane the width from the right outer pore of ambulacrum D across interambulacrum C to the left outer pore of ambulacrum B is 13 mm., this being only slightly more than the width given for the interambulacrum itself. There are two columns of plates throughout the interambulacral area, and, as gathered from the impressions on the mold, there are fourteen plates in each interambulacral column. In each of the two lateral interambulacral areas, A and E, which are partially visible, there are five plates in place, and these from their height also indicate that there would be about fourteen plates in one column. This is a very large number for the genus and also for the family. In Recent *Eucidaris tribuloides* I have found fourteen plates in a column, but such a number is rarely attained in the Cidaridae. In the dorsal portion of interambulacrum C there are two fragmentary plates (text-fig. 239c) which meet in a median angular suture, as usual in cidarids. As seen at one point dorsally where the plates are preserved, the interambulacral plates bevel strongly over the ambulacrals on the adradial suture (text-fig. 239e). It is from this structure that I refer the species to the genus *Miocidaris*. The interambulacral plates at the mid-zone measure 2.5 mm. in height by about 6 mm. in width, measuring to the middle of the interambulacral area, and about 0.75 mm. in thickness. The measurement of the height and width is taken from the internal mold, as no plate preserved is complete in width, but the height as given is confirmed by the plates which are in place. The most complete plate preserved at the mid-zone in area E measures 4 mm. in width, but its admedian portion is hidden beneath the hard siliceous matrix. Unfortunately the worn plates that exist do not show a complete outline nor surface characters,

excepting that one plate in area E shows the remains of the perforation of a primary tubercle. In the mold the horizontal boundaries of the interambulacral plates are fairly well defined as depressed furrows extending from the adradial suture to near the middle of the interambulacrum, but the median sutures are mostly indistinct. On examining the interior of a half-grown *Eucidaris tribuloides* it is seen that the horizontal boundaries of the interambulacral plates stand out as prominent ridges, whereas the median boundaries do not, and this may well account for the differences seen in the mold. The mold of each plate presents a slightly convex form with a small mammillate elevation (text-figs. 239a, b) which corresponds with the concave form and deeper impression beneath the tubercle on the interior of the plate of a cidarid, as seen well in an immature *Eucidaris tribuloides*.

This species is of exceptional interest, as it is the first sea-urchin recorded from the Palaeozoic of America with two columns of plates in an interambulacrum; also it extends the range of the genus *Miocidaris* and the order Cidaroida to the Lower Carboniferous, whereas previously they were not known below the Permian. The occurrence of this type with two columns of interambulacral plates in the Lower Carboniferous adds support to my view, as earlier published (1896, p. 237, table facing p. 242) and maintained in this memoir, that two columns of plates in an interambulacral area is a primitive structure and types having this structure are to be derived from an ancestor with one column of plates in an area, and not to be derived from an ancestor with many columns in an interambulacral area, as has been usually held (p. 211).

Miocidaris cannoni, which I take pleasure in naming for Mr. Cannon, from whom I received the specimen, differs from other species of the genus in its large size and numerous interambulacral plates in a column. The number of plates is perhaps sufficient to justify generic distinction, but as the surface characters are unknown, it seems best to place the species in the genus *Miocidaris*, to which at least it is very closely allied. While this species occurs in the Lower Carboniferous and is therefore very much older than *Miocidaris keyserlingi* of the Permian, it is placed higher than that species because, on account of having a large number of plates in an interambulacral column, it is farther removed from the primitive than is *keyserlingi* with a smaller number of plates in a column.

Mr. Cannon informs me that he recently obtained the specimen, and that it is from the Millsap Formation of the Rocky Mountain Lower Carboniferous, from near Denver, Colorado. The specimen was collected by Mr. George Day, and was found in one of the loose chert concretions in the Platte River drift. While not in place, material of this lithological character according to Mr. Cannon and other authorities is known in Colorado only from the Millsap Formation, which occurs as outcrops in the Front Range. Girty (1903, pp. 162, 167) ascribes the Millsap Formation to the Mississippian, or Lower Carboniferous. The specimen is now in the collection of the Museum of Comparative Zoölogy 3,201.

Order ECHINOCYSTOIDA nom. nov.

Cystocidaridae Zittel, 1879, p. 480; A. Agassiz, 1881, p. 81.

Cystocidaroida Dunean, 1889a, p. 20; Jackson, 1896, p. 242; Gregory, 1900, p. 300.

Cysticaroida Tornquist, 1897, p. 730.

Professor Zittel based his name of the order on the name *Cystocidaris* which he gave to replace the genus *Echinocystites* of Wyville Thomson. As *Cystocidaris* is a synonym and cannot stand, neither, by the rules of nomenclature, can the name of the order based on it; I therefore substitute a new name for this order.

Test spheroidal or flattened, apparently irregular, with the anus in an interambulacral area. Ambulacra narrow, with two or four columns of low plates in an area. Interambulacra wide, with numerous, eight or more, columns of very thin, rather irregular polygonal plates in an area. Lantern well developed, typically echinoid in character. The known specimens of the two families and genera of this order are imperfectly preserved, therefore are incompletely known; further knowledge is much to be desired.

Family PALAEODISCIDAE Gregory.

Palaeodiscidae Gregory, 1897, p. 133; Lambert and Thiéry, 1910, p. 117.

Test depressed, nearly or quite circular. Gregory says pentagonal, but I think this is hardly correct. Ambulacra narrow, composed of two columns of low plates in each area, with pores throughout the areas, not imperforate ventrally, as Gregory says. Anus eccentric in an interambulacrum at a considerable distance from the apex and quite near the mid-zone, as figured by Spencer (1904, Plate 1, fig. 1). Earlier Gregory (1897) said that the anus is central, but he did not figure it. I have not seen a specimen showing this structure. A typical echinoid lantern exists. There is only one genus and species.

PALAEODISCUS Salter.

Palaeodiscus Salter, 1857, p. 332; Zittel, 1879, p. 453; Dunean, 1889a, p. 6; Gregory, 1900, p. 301; Lambert and Thiéry, 1910, p. 117.

With characters of the family. The type and only recognized species is *P. ferox* Salter, of the Silurian of England. *Palaeodiscus gothicus* is considered under *Incertae Sedis*.

***Palaeodiscus ferox** Salter.

Plate 18, figs. 1-5.

Palaeodiscus ferox Salter, 1857, p. 332, Plate 9, fig. 6; Wyville Thomson, 1861, p. 13, Plate 4, figs. 6, 7; Neumayr, 1881, p. 155, Plate 1, fig. 8; Gregory, 1897, p. 129, text-figs. 4, 5; Plate 7, figs. 5a-5b; Sollas, 1899, p. 701, text-figs. 6-11; 1899a, p. 277; Spenceer, 1904, p. 31, text-figs. 1-8, Plate 1, fig. 1; Lambert and Thiéry, 1910, p. 117.

The test is very much flattened in known specimens, as it probably was in life, and is nearly or quite circular in outline. Ambulacra are narrow with two columns of low plates, of which about four equal the height of an adambulacral plate. The pore-pairs are about in the middle of the plates and are clearly developed ventrally, as shown in my figures. I cannot understand why Dr. Gregory should say (1897, p. 129) that there are no pores through the plates, but that the podia must have been extended between the sutures. The specimens Dr. Bather kindly loaned me, from the British Museum, have pores distinctly through the plates as in other typical echinoids. Interambulacra with many, apparently about eight or nine columns of highly irregular plates, and, as pointed out by Spencer, the primordial plates are in the basicoronal row. The plates were evidently extremely thin and bore numerous fine acicular spines. On the peristome there are ten columns of ambulacral plates only. The apical disc is unknown but I think Gregory is not justified in saying probably absent. It is not known to be absent in any echinoid. The lantern, as shown by Sollas, is of the typical character, inclined, with pyramids, epiphyses, braces, and even compasses, as figured by Sollas.

Lower Ludlow, Silurian, near Ludlow, and Church Hill, Leintwardine, England; British Museum, a number of specimens, including those described by Gregory (1897); Oxford Museum.

This species, representing its genus and family, has been much discussed, and on account of imperfections of material, a number of points are still uncertain. Salter referred the type to starfishes, and Zittel (1879, p. 453) followed him. Several authors have considered the type as intermediate between starfishes and echinoids, and as a primitive type. I think recently published material distinctly shows that Palaeodiscus is an echinoid, has no connection with starfishes, and is not a primitive type.

As regards the ambulacrum, I find no evidence of pores between the plates, as claimed by Gregory, but rather they are through the plates as usual in echinoids. As regards the roofing system of plates described by Sollas and Spencer, they claim that above the typical ambulacral plates (Sollas, 1899, p. 705, fig. 9) there is a set of narrower plates roofing over the outer flooring plates. This narrower set is supposed to correspond with the ambulacral plates of a sea-urchin, superposed on those of a starfish, and thus the connection of the two groups is supposed to be solved. It is a somewhat novel morphological reasoning from the facts. It would require that we consider the wider or flooring ambulacral plates of Palaeodiscus (which Sollas, 1899, pp. 705, 706, considers the equivalent of the ambulacral plates of later Echini), as equivalent to the adambulacral plates of a starfish grown across the area and meeting in the center line, but I see no basis for such an argument. I think the roofing plates of Sollas are the narrower ambulacral plates of the dorsal side brought in mechanical contact with the wider ventral plates by the flattening of the test, exactly as shown in area B of *Hyattechinus rarispinus* (Plate 23, fig. 1). The interambulacra are typically echinoid, and from the large number of columns of plates appear to me to indicate a specialized, not a primitive type. Ambulacral

plates on the peristome are a typical echinoid character. The inclined lantern is of the typical character seen in Palaeozoic species, is purely echinoid, and has no relation to the structure of any known starfish. There are grooved teeth, narrow epiphyses, braces, and even rather deeply forked compasses as shown by Sollas (1899, text-figs. 7, 8) whose figure 7 is in part reproduced in my Plate 18, fig. 5. Some knowledge of ocular and genital plates is much to be desired, and the position of the anus should be more positively settled. If Spencer is correct in showing the anus in an interambulacral area, we must consider Palaeodiscus a peculiar and irregular echinoid. If the anus is in the center dorsally, as Gregory says (1897, p. 129), then Palaeodiscus is not irregular, is wrongly placed in this order, and could properly find a place in the Lepidocentridae, from which it differs essentially in this character only.

Family ECHINOCYSTIDAE Gregory.

Echinocystidae Gregory, 1897, p. 133; Lambert and Thiéry, 1910, p. 118.

Test spheroidal, ambulacra narrow with at the mid-zone four columns of plates which are demi- and occluded. Interambulacra broad with many columns of irregular plates. Plates thin with small primary and secondary tubercles and spines. Apical plates doubtful, but the anus is eccentric in an interambulacrum. A well developed typical echinoid lantern exists. One genus and species.

ECHINOCYSTITES Wyville Thomson.

Echinocystites Wyville Thomson, 1861, p. 106; Duncan, 1889a, p. 20; non Hall, 1865; 1868a, p. 316.

Cystocidaris Zittel, 1879, p. 480.

Echinocystis Gregory, 1897, p. 124; Lambert and Thiéry, 1910, p. 118.

With characters of the family. The type-species is *E. pomum* Wyville Thomson, from the Silurian of England.

**Echinocystites pomum* Wyville Thomson.

Plate 16, fig. 4; Plate 18, figs. 6-8; Plate 20, figs. 1-4.

Echinocystites pomum Wyville Thomson, 1861, p. 109, Plate 3, figs. 1-3; Plate 4, figs. 1-5.

Echinocystites uva Wyville Thomson, 1861, p. 110, Plate 4, figs. 4, 5.

Cystocidaris pomum Zittel, 1879, p. 480.

Cystocidaris uva Zittel, 1879, p. 480.

Echinocystis pomum Gregory, 1897, p. 124, text-figs. 1-3, Plate 7, fig. 4; Sollas, 1899, p. 707, text-figs. 12-14; Klem, 1904, p. 13; Lambert and Thiéry, 1910, p. 118.

Echinocystis [*pomum*] Spencer, 1904, pp. 31, 34.

Echinocystis uva Lambert and Thiéry, 1910, p. 118.

The test is spheroidal, ambulacra narrow with four columns of plates in an area, demi- and occluded, pore-pairs are biserial and pass through about the center of each plate. Inter-

ambulacra wide with in each area about eight columns of very irregular thin polygonal plates which bear small primary and secondary tubercles and spines.

The apical plates are doubtful; but a madreporite is described by Wyville Thomson and Gregory in an interambulaerum. As this is a unique condition in Echini and morphologically difficult to understand, it may not be too much to suggest that in the squeezing of this rather badly preserved material, it may have got displaced. According to Wyville Thomson, the anus with apparently periproctal plates is in an interambulaerum, making it an irregular type. The lantern is well developed, and Gregory shows that it has typical echinoid pyramids. The material I have seen is so crushed and badly preserved that it is very difficult to make out much structure. There seems no reason for considering this type as presenting any possible connection with starfishes, or as a primitive type. Its four columns of ambulacral plates, and especially its eccentric anal area, would lead one to consider it a specialized and irregular rather than a primitive echinoid.

Lower Ludlow, Silurian, Leintwardine, England; a very fine specimen is in the Museum of Practical Geology, London 7,385, one of Sir Wyville Thomson's originals. This is shown in Plate 16, fig. 4, from a photograph kindly sent me by Dr. Kitchin. There are several specimens in the British Museum, part of which Dr. Bather kindly loaned me for study. Oxford Museum (Sollas).

Order PERISCHOECHINOIDA M'Coy.

Perischoechinida M'Coy, 1849, p. 251; 1854, p. 114; Jackson, 1896, p. 239.

Tessellati Desor, 1858, p. 152.

Perischoechinidae Lovén, 1874, p. 39; A. Agassiz, 1874, p. 644; 1881, p. 3; Zittel, 1879, p. 481.

This large order consists of regular Palaeozoic Echini in which the periproct is within the oculo-genital ring. The test is of various shapes and horizontal outline throughout the ambitus, but is usually spheroidal. Ambulacral areas are narrow, or wide, with in each area from two to twenty columns of plates, all simple and all bearing one pore-pair each. There are from three to fourteen columns of plates in each interambulacral area. Usually the plates of the adambulacral columns are pentagonal, and those of the median columns hexagonal, except where new columns are introduced, and in young plates dorsally. Plates may be thick, or thin, and bear primary perforate tubercles and spines with secondaries, or the latter only. Plates of the corona may be imbricate or not; when imbricate, ambulacral plates imbricate adorally and bevel under the adambulacral plates laterally. Interambulacral plates imbricate aborally and from the center laterally and over the adjacent ambulacral plates. When plates are not imbricate, then the sides of the plates are as nearly parallel as is mechanically possible in a curved test, but they may be very far from parallel, as in the thick-plated *Melonechinus*. When there is no imbrication, the ambulacral plates may bevel over the adambulacral, as is char-

acteristic of the Palaeoechinidae. As far as the evidence goes, the primordial ambulaeral plates are around the mouth on the peristome, and the primordial interambulaeral plates are in the basicoronal row, or are resorbed in the advance of the peristome. The peristome is plated with many rows of ambulaeral plates only, or may in addition have non-ambulaeral plates situated interradially. Oculars are usually imperforate and all insert, but rarely are perforate, and exceptionally one or more to all may be exsert. Genitals usually have three or more to numerous genital pores; the madreporite is rarely distinguishable. The periproct is covered with many angular plates which fill the area. The lantern is inclined, subtending an angle of about 90 degrees, and as in modern regular Echini, is composed of forty pieces. The teeth are grooved, pyramids wide-angled, foramen magnum moderately deep, epiphyses narrow, capping the half-pyramids; brace and compass as in modern Echini. This group includes all Palaeozoic Echini excepting those already considered, and comprises the best known and, excepting Bothriocidaris, the most interesting genera of these ancient formations (pp. 361-363).

Family ARCHAEOCIDARIDAE M'Coy.

Echinocrinoidea T. and T. Austin, 1842, p. 111.

Archaeocidaridae M'Coy, 1849, p. 253; Lovén, 1874, p. 42.

Lepidocidaridae Bather, 1907, p. 456.

The test is spheroidal or depressed; ambulaera are narrow, with in each area two columns of plates imbricating moderately adorally and beveled under the adambulaerals. Pore-pairs are uniserial or slightly biserial. There are from four to eight columns of plates in each interambulacral area, plates are large, thin, imbricating moderately aborally and laterally and over the ambulaerals. The interambulaeral plates bear a large central perforate primary tubercle and large serobicule, with a large primary spine, also secondary tubercles and spines. The base of the corona is resorbed in the advance of the peristome, strongly so in Archaeocidaris. The peristome has many rows of ambulacral and at least in Archaeocidaris interradiial non-ambulacral plates as well. Oculars and genitals unknown or very doubtful. There are three genera in the family. The name Lepidocidaridae was proposed by Dr. Bather to take the place of Archaeocidaridae on the basis of giving up Archaeocidaris for the earlier but misleading name of Echinocrinus. As I have decided to cling to the old established name Archaeocidaris, pending possible consideration of the matter, I therefore retain also the name Archaeocidaridae.

EOCIDARIS Desor.

Eocidaris Desor, 1858, p. 155; Lovén, 1874, p. 42; Bather, 1909, p. 44; (pars) Lambert and Thiéry, 1910, p. 126.

This genus, most imperfectly known, is based on isolated interambulacral plates and primary spines. Interambulaeral plates are probably hexagonal, or pentagonal in adradial

columns, as in *Archaeocidaris*, but the shape is not definitely known in the only species attributed to this genus. The plates have a large central perforate tubercle and scrobicule and marginal secondary tubercles, like *Archaeocidaris*, but differ from that genus in that there is no basal terrace within the scrobicular circle. Primary spines are stout.

This genus has recently received most careful consideration from Dr. Bather, and he concludes from all the evidence that of known species, only the *Cidaris laevispina* and *scrobiculata* Sandberger are referable to it. Many species have been referred to the genus by various authors, but I agree with Bather that all excepting those noted, are clearly referable to other genera.

This genus is closely related to *Archaeocidaris*, from which, so far as known, it differs only in the absence of the basal terrace. As the known species occur in the Devonian, it is older than *Archaeocidaris*, which first appears in the Lower Carboniferous. The youthful plates in the dorsal region in *Archaeocidaris rossica* have not acquired the basal terrace, and in this feature are therefore like the condition ascribed to the geologically older but closely related *Eocidaris*. The type species is *E. laevispina* (Sandberger) from the Devonian of Germany.

****Eocidaris laevispina* (Sandberger).**

Plate 15, figs. 11a-d, 12.

Cidaris laevispina Sandberger, 1850-'56, p. 382, Plate 35, figs. 2-2d.

Cidaris scrobiculata Sandberger, 1850-'56, p. 382, Plate 35, fig. 3.

Eocidaris laevispina Desor, 1858, p. 156, Plate 21, figs. 18-21; Lovén, 1874, p. 43; Klem, 1904, p. 69;

Bather, 1909, text-fig. 1, p. 51, Plate 1, figs. 1-4; Lambert and Thiéry, 1910, p. 126.

Eocidaris scrobiculata Desor, 1858, p. 157, Plate 21, fig. 17; Lovén, 1874, p. 43; Klem, 1904, p. 71; Bather, 1909, Plate 1, fig. 5; Lambert and Thiéry, 1910, p. 126.

This species, the only one which I recognize in the genus, is based on isolated interambulacral plates and spines. Bather recently borrowed Sandberger's original specimens from the Wiesbaden Museum and figured them, and my figures are based on his. The interambulacral plates show beveled edges, indicating strong imbrication. As the outlines of the plates are not preserved, their shape, hexagonal or otherwise, cannot be definitely stated. The central perforate mamelon is elongate, scrobicular area large, with no trace of a basal terrace; secondary tubercles are rather widely and irregularly spaced on the extra-scrobicular area excepting the beveled edge, which apparently in life was overlapped by the next adjacent plate. Primary spines are stout, cylindrical, smooth, with a weakly developed annulus, which does not show vertical fluting as in the typical milled ring of *Archaeocidaris*.

The holotype of *Cidaris scrobiculata* Sandberger is a single interambulacral plate (Plate 15, fig. 12), and is so close to *laevispina* in character, that it is here included as a synonym. As Bather says (1909, p. 53), "The Sandbergers may have been right in regarding this specimen as

of a different species; but if one were to maintain that it came merely from a different part of the test of *C. laevispina*, I do not see how it could be disproved."

Sandberger's material all came from the Middle Devonian, Stringocephalus Limestone of Villmar, and is in the Wiesbaden Museum as above noted. Two interambulacral plates from the Devonian of Villmar are in the Museum of Comparative Zoölogy 3,192, from the Schültze Collection.

ARCHAEOCIDARIS M'Coy.

Echinocrinus L. Agassiz, 1841, p. 15; Bather, 1907; 1909; 1909a, p. 264.

Archaeocidaris M'Coy Mss., 1844, p. 173; M'Coy, 1849, p. 252; Young, 1873; 1876; Lovén, 1874, p. 43;

Duncan, 1889a, p. 11; A. Agassiz, 1881, pp. 79, 80; Lambert and Thiéry, 1910, p. 124.

Palaeocidaris L. Agassiz and Desor, 1846-'47, p. 340.

Cidarotropus Pomel, 1883, p. 113; Lambert and Thiéry, 1910, p. 125.

Permocidaris (pars) Lambert, 1899a, pp. 39, 47; Lambert and Thiéry, 1910, p. 127.

The test is depressed spheroidal, ambulacra narrow, sinuous in outline, conforming to the outline of the massive adradial plates. Ambulacral plates are low, of uniform character, imbricating moderately adorally and beveled strongly under the adradials; the pore-pairs are uniserial. Interambulacra, in all species where a fairly complete test is known, with four columns of plates in each interambulacral area. The adradial plates are pentagonal, but rounded on the adradial suture line; plates of the intermediate columns are hexagonal. Each plate bears a prominent perforate median tubercle with a wide scrobicular area and a basal terrace, though this terrace, being a slight feature, may be worn off in eroded plates and is absent (*A. rossica*) in young plates dorsally.

Beyond the border of the scrobicular circle are secondary tubercles which differ in their number and in the extent of surface which they cover both in different species and somewhat in plates of different parts of the test in the same species (*A. rossica*). Primary spines are relatively large, often very large, with a concave base, marked milled ring, and a shaft tapering or enlarged, smooth or ornamented with striations, spinules, or rarely flange-like vertical ridges. The primordial ambulacral plates are on the peristome around the mouth, and the primordial interambulacral plates with additional rows are resorbed in the advance of the peristome, as there are four plates in the basicoronal row (Plate 9, figs. 7, 8). The peristome is covered with radially situated ambulacral and interradially situated non-ambulacral plates, all small and imbricating adorally (text-fig. 47, p. 80). Ocular and genital plates are doubtful, periproct with many small angular plates. The lantern is well developed, of the typical Palaeozoic character (Plate 12, figs. 1-8). Of this genus a few species are known fairly completely,¹ but there are numerous species described from incomplete material, often only one or more dis-

¹ The best known species, especially as regards the test, are *Archaeocidaris wortheni*, *legrandensis*, *rossica*, *agassizi*, and *urii*.

sociated plates and spines. Such are most unsatisfactory, often difficult to distinguish, and doubtless there are too many recognized species, of little interest except as expressing the geographical distribution of the genus. With available material the best way, it seems, is to group the species on the basis of spine characters, associating those species that have smooth spines, those in which the spines bear low nodose spinules, and those with spinules more elevated and directed at right angles to the shaft of the spine, or pointing distally, or spines with lateral flanges, spines triangular in section, or spines inflated. This has at least some resemblance to a natural classification. The type species, as indicated by Bather (1907, p. 453), is *A. urii* (Fleming) from the Lower Carboniferous of Europe.

The genus *Archaeocidaris* is structurally closely related to the *Cidaridae*, but is more complex in that there are four columns of plates in an interambulacral area instead of two columns. *Archaeocidaris* may be derived from some early cidarid, perhaps Devonian or Silurian. The fact that I describe a true cidarid (*Miocidaris cannoni*) from the Lower Carboniferous, which is geologically as early as any species of *Archaeocidaris* known lends weight to this argument. (See pp. 70, 77, 80, 184, 223, 361, 363.)

Lambert and Thiéry (1910, pp. 124, 125) under what I consider as *Archaeocidaris* recognize two genera, *Archaeocidaris*, which they say has interambulacra formed of from five to eight columns of plates, and *Cidarotropus*, in which they say that the interambulacra are formed of four columns of plates. I know no species of *Archaeocidaris* with more than four columns of plates in an interambulacral area, and many of the species which they list in one of their two definite genera are known only fragmentarily from isolated plates so that the number of columns in an area is quite unknown.

The proper name to apply to this genus is open to question. As shown positively by my friend, Dr. Bather, on the basis of priority, *Echinocrinus* is the correct name. This name, however, is misleading, was based by Professor Agassiz on a misconception of affinities, and has been abandoned for some sixty years in favor of the entirely appropriate *Archaeocidaris* of M'Coy. It is not a case of *Archaeocidaris* being preoccupied but simply of priority. To revive the old name, *Echinocrinus*, in accordance with rules of nomenclature, will make confusion at present and in future, and no gain to any one.

As Dr. Bather justly says (1909a, p. 264), "While there can be no doubt as to the consequences of the rules, this seems to me just one of those cases that should be settled by a properly constituted authority in defiance of the rules." Such being the case, pending the action of some formal authority, I feel it best to follow the conservative action of retaining the entirely satisfactory and thoroughly established name *Archaeocidaris*. The name *Palaeocidaris* Agassiz and Desor is a pure synonym, *Cidarotropus* Pomel with *Archaeocidaris wortheni* Hall as the type, and *Permocidaris* Lambert with *Archaeocidaris forbesiana* (Koninek) as the type, I do not recognize as distinct genera.

With present knowledge it is impracticable to make a key for distinguishing each of the numerous and imperfectly known species of *Archaeocidaris*. An attempt has been made, however, to give a key that will distinguish groups of species which have similar characters as regards the structure of the primary spines, and these will serve as an aid in identifying any case in hand in which the spines are in place.

*Key to the Groups of Species of Archaeocidaris.*¹

Spines circular in section, smooth, without spinules or nodose elevations:

<i>A. wortheni</i> Hall (America), p. 259.	<i>A. longispina</i> Newberry (America), p. 261.
<i>A. legrandensis</i> Miller and Gurley (America),	<i>A. glabrispina</i> (Phillips) (Europe), p. 261.
p. 260.	

Spines circular or rarely elliptical in section, with numerous short spinules which are nearly uniform in size and are directed distally:

<i>A. nereis</i> (Münster) (Europe), p. 262.	<i>A. aculeata</i> Shumard and Swallow (America),
<i>A. rossica</i> (Buch) (Europe), p. 263.	p. 268.
<i>A. agassizi</i> Hall (America), p. 266.	<i>A. shumardana</i> Hall (America), p. 268.
<i>A. illinoisensis</i> Worthen and Miller (America),	<i>A. edgarensis</i> Worthen and Miller (America),
p. 266.	p. 269.
<i>A. coloradensis</i> nom. nov. (America), p. 267.	<i>A. newberryi</i> Hambach (America), p. 269.
<i>A. keokuk</i> Hall (America), p. 267.	<i>A. trudifer</i> White (America), p. 269.
<i>A. gracilis</i> Newberry (America), p. 267.	

Spines circular in section, with large thorn-like spinules directed distally:

<i>A. norwoodi</i> Hall (America), p. 270.	<i>A. cratis</i> White (America), p. 272.
<i>A. paradoxa</i> (Eichwald) (Europe), p. 270.	<i>A. acanthifera</i> Trautschold (Europe), p. 272.
<i>A. mucronata</i> Meek and Worthen (America),	<i>A. pizzulana</i> Gortani (Europe), p. 272.
p. 271.	<i>A. megastyla</i> Shumard and Swallow (America),
<i>A. dininnii</i> White (America), p. 271.	p. 273.

Spines with two lateral wing-like expansions:

- A. biangulata* Shumard and Swallow (America), p. 273.

Spines densely covered with long spinules directed distally:

<i>A. ornata</i> (Eichwald) (Europe), p. 274.	<i>A. ourayensis</i> Girty (America), p. 274.

Spines triangular in section, with spinules on the angles and directed distally:

<i>A. triplex</i> White (America), p. 274.	<i>A. triserrata</i> Meek (America), p. 275.
<i>A. triserialis</i> (M'Coy) (Europe), p. 275.	

¹ A number of species of *Archaeocidaris*, or of species referable to that genus, which are not known well enough to intercalate in the systematic series are taken up later. These are: *Archaeocidaris konincki*, *ladina*, *scotica*, *selwyni*, *sizi* and *trautscholdi*, *Cidarites tennesseae*, *Echinocrinus anccps*, *spinosus* and *striatus*, considered under *Incertae Sedis*. Also *Archaeocidaris tirolensis*, *Echinocrinus cidariformis* and *pomum* considered under *Nomina Nuda*.

Spines with four vertical rows of spinules:

A. rankini Young (Europe), p. 276.

Spines with six vertical rows of spinules:

A. prisca (Münster) (Europe), p. 276.

Spines with many vertical ridges, which bear spinules directed distally:

A. werrekei Tornquist (Europe), p. 276.

A. halliana (Geinitz) (Europe), p. 279.

A. urii (Fleming) (Europe), p. 276.

A. muensteriana (Koninek) (Europe), p. 280.

Spines inflated, club-shaped:

A. forbesiana (Koninek) (India), p. 280.

A. sp. b. Girty (America), p. 281.

A. spinoclavata Worthen and Miller (America),

A. clavata (Eichwald) (Europe), p. 282.

p. 281.

****Archaeocidaris wortheni* Hall.**

Text-figs. 26, p. 70; 47, p. 80; Plate 8, figs. 5, 6; Plate 9, figs. 6-11.

Archaeocidaris wortheni Hall, 1858, p. 700, Plate 26, figs. 4a-4g; Lovén, 1874, p. 43; Quenstedt, 1875, p. 372, Plate 75, figs. 10-14; Zittel, 1879, p. 485, figs. 343a-343e (not 343d, which in this and other editions is evidently *Archaeocidaris keokuk* Hall); (?) Walcott, 1884, p. 212; Keyes, 1894, p. 128, Plate 17, figs. 3a, 3b; 1895, p. 187, Plate 20, figs. 3a, 3b; Jackson, 1896, p. 214, Plate 8, figs. 43-46; Tornquist, 1897, p. 770, Plate 21, fig. 5; Klem, 1904, p. 61.

Cidarotropus wortheni Pomel, 1883, p. 113; Lambert and Thiéry, 1910, p. 125.

Test spheroidal, but flattened mechanically in the known specimens. The ambulacra are narrow, sinuous, conforming to the outline of the adambulacral plates. Ambulacral plates are low, imbricating moderately adorally, beveled under the adradials, with pore-pairs uniserial. Interambulacra are broad, with four columns of plates in each area, imbricating moderately aborally and from center laterally and over the ambulacrals. There are four plates in the basicoronal row of each interambulacral area, indicating an extensive resorption of the corona in the advance of the peristome (p. 73). Interambulacral plates hexagonal, except the adradials, somewhat wider than high, with a wide scrobicular area as seen well in Plate 8, fig. 5, and Plate 9, fig. 9. Secondary tubercles are limited to a narrow border parallel to the edges of each plate. The primary spines are long, slender, slightly arcuate, from the milled ring tapering to the distal end. Small secondary spines are associated with the secondary tubercles. The peristome has ambulacral plates radially and numerous scale-like non-ambulacral plates interradially situated, all imbricating adorally. The dorsal area is known only partially (Plate 8, fig. 6). The lantern is of the typical character of the genus (Plate 9, fig. 10).

St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. The cotypes and several other specimens including one fine slab with ten tests are in the American Museum of Natural

History; specimens from the same locality in the Museum of Comparative Zoölogy; F. Springer Collection; (?) Lower Carboniferous, Eureka District, Nevada (Walcott).

The type specimen in the American Museum of Natural History is one of the most nearly complete specimens known in the genus, and measures 53 mm. in diameter through J, E (Plate 8, figs. 5, 6; Plate 9, figs. 6-8). It is not quite complete in the basicoronal row, but excepting area I is very nearly so. In areas A and C, in the basicoronal row, the plates of columns 1 and 4 are nearly whole, whereas the plates of columns 3 and 2 are small, representing only the dorsal part of each plate, of which the ventral portion has been resorbed. In areas E, G, and probably I, in the basicoronal row, the plates of columns 1 and 3 are small, of which the greater part has been resorbed, whereas the basicoronal plates of columns 4 and 2 are nearly complete plates with slight ventral resorption. A similar condition is shown in *A. rossica* (text-fig. 239 bis, p. 264), and in part in *A. urii* (Plate 15, fig. 1). This alternation of large and small plates in the basicoronal row is due to the cutting off of the ventral part of the plates by resorption in the advance of the peristome (text-fig. 26, p. 70). The relative position of the large and small plates differing by the two arrangements I earlier ascribed (1896, p. 219) to the relative position of the introduction of column 4, as seen in the restoration (Plate 9, fig. 8). By restoring schematically the plates that have been resorbed, we see that if column 4 is introduced to the right of the center, then in the basicoronal row the plates of columns 1 and 4 are large; or if column 4 is introduced to the left of the center, then in the basicoronal row the plates of columns 1 and 3 are small. There are no gill-slits on the peristomal border (p. 223).

The peristome in this fine specimen is the most nearly complete one known in the genus. There are two columns of ambulacral plates in an area, doubtless formed by flowing down from the corona as in *Cidaris* (text-figs. 46, 47, p. 80). There are also many irregular scale-like non-ambulacral plates imbricating strongly. These plates, it is believed, are formed in place, and are not derived from the corona, as discussed under consideration of the peristome (p. 86). It was in this specimen that secondary spines were first shown in the genus. A complete lantern is not known, but the essential parts are shown in Plate 8, fig. 6, and Plate 9, fig. 10. The pyramid is wide-angled with rather deep foramen, epiphyses narrow, capping the half-pyramids.

****Archaeocidaris legrandensis* Miller and Gurley.**

Plate 8, figs. 7, 8; Plate 9, figs. 12, 13; Plate 10, figs. 3, 4.

Archaeocidaris legrandensis Miller and Gurley, 1889, p. 373, Plate 10, fig. 15; Keyes, 1895, p. 185; Klem, 1904, p. 50; Lambert and Thiéry, 1910, p. 124.

Eocidaris blairi Miller, 1892, p. 683, Plate 22, fig. 1; Klem, 1904, p. 67.

Test in side view (Plate 8, fig. 8) is only moderately compressed, and measures 26 mm. in diameter, and the ventral view (Plate 8, fig. 7) is of about the same size. The ambulacral plates are not preserved, but their position is located by the outlines of the adambulacrals.

There are four columns of plates in each interambulacrum; these plates are low, wide hexagons, the basal terrace is clearly marked in the scrobicular area (Plate 8, fig. 7). Spines are smooth, tapering, slightly arcuate. Secondary spines are on the borders of plates associated with secondary tubercles (Plate 9, fig. 13).

The type of *A. legrandensis* (Plate 10, fig. 4) is a very small and not well preserved specimen, but it has low hexagonal plates and smooth, slightly arcuate spines. As I cannot distinguish this species from *blairi*, therefore *legrandensis*, which is the older name, has priority. Miller was mistaken in referring *blairi* to the genus *Eocidaris*, for since the basal terrace is perfectly clearly marked, this feature indicates that it is an *Archaeocidaris*.

The type specimen of *legrandensis* is from the Kinderhook Group, Lower Carboniferous, Le Grand, Iowa, now in Chicago University Collection 6,198. A second specimen from the same locality and collection is no. 12,314. The specimens originally described as *Eocidaris blairi*, here considered a synonym, are from the Keokuk Group of Boonville, Missouri, now in Chicago University Collection 8,855. Keokuk Group, Canton, Indiana, a ventral view, with some spines in place, Museum of Comparative Zoölogy 3,198; Keokuk Group, Bono, Lawrence County, Indiana, Museum of Comparative Zoölogy, two good specimens, one (3,199) showing four columns of plates in each interambulacral area and the other (3,200) spines in place. In the Springer Collection a specimen 8,024, from the Kaskaskia Group, Pulaski County, Kentucky, and one 8,083, from the Keokuk Limestone of Bono, Indiana, are referred to this species.

****Archaeocidaris longispina* Newberry.**

Plate 10, fig. 1.

Archaeocidaris longispina Newberry, 1861, p. 116, Plate 1, figs. 1, 1a; Keyes, 1895, p. 191; Klem, 1904, p. 51; Lambert and Thiéry, 1910, p. 124.

Known only from primary spines which are long, smooth, narrow above the milled ring, inflated in the lower half and thence tapering to a point. Newberry says 2.5 to 3.5 inches in length. The longest of the three type specimens measures 63 mm. in length and 6 mm. in diameter at the widest part.

Crinoidal Limestone, upper part of Carboniferous (Coal Measures), on the banks of the Colorado River. The type consists of three spines on one slab. It is in Columbia University Collection 6,419 G, and bears the label "Coal measure limestone, North Arizona."

****Archaeocidaris glabrispina* (Phillips).**

Plate 10, figs. 2a-2b, 8a-8c, 9.

Cidaris glabrispina Phillips, 1836, p. 208.

(?) *Echinocrinus glabrispina* McCoy, 1844, p. 173.

Archaeocidaris stellifera Bailey, 1877, p. 18, text-figs. a-c.

Archaeocidaris laevis Trautsehoid, 1879, p. 7, Plate 2, fig. 1 u (the number of the figure is wanting on Plate).
Archaeocidaris glabrispina Etheridge, 1888, p. 221; Klem, 1904, p. 62; Lambert and Thiéry, 1910, pp. 124, 125.

Primary spines smooth, straight, swollen about the middle, above which tapering to a point. Interambulaeral plates hexagonal, about 5.2 mm. wide, and wider than high.

The species *stellifera* and *laevis* may differ from *glabrispina* if complete material is found; but with present evidence they cannot be distinguished. The plates figured by Baily (my Plate 10, figs. 8a-8e) are so schematic as probably to be unreliable.

Lower Carboniferous, the original locality given by Phillips is Northumberland; Bundaran, Ireland, in the Griffith Collection, Science and Arts Museum, Dublin (this is doubtless the material referred to by M'Coy, 1844, p. 173). The specimen figured (Plate 10, fig. 2) is from Hook Head, Ireland, and is in the Sedgwick Museum, Cambridge, England; Clitheroe, England, British Museum Collection E 10,691, this is a small slab with spines and interambulacral plates; Frome, England, a small slab with spines and interambulaeral plates, British Museum Collection 38,550; Ireland, from one or more of several localities given by Baily for his *A. stellifera*, which is considered a synonym of *glabrispina*, as indeed Baily suggested as possible; Miatschkowa, Province of Moscow, Russia (Trautsehoid, his *A. laevis*).

****Archaeocidaris nereis* (Münster).**

Plate 10, figs. 5a-5d, 6, 7.

Cidarites nereis Münster, 1839, p. 40, Plate 3, figs. 6a-6d; Koninek, 1842-'44, [description of] Plate E.

Cidarites protei Münster, 1839, p. 40.

Echinocrinus nereis L. Agassiz, 1841, p. 16; d'Orbigny, 1850, p. 154.

Echinocrinus protei L. Agassiz, 1841, p. 16; d'Orbigny, 1850, p. 154.

Cidarites nereis Koninek, 1842-'44, p. 34, Plate E, figs. 1a-1i.

Palaeocidaris nereis L. Agassiz and Desor, 1846-'47, p. 340.

Palaeocidaris protei L. Agassiz and Desor, 1846-'47, p. 340.

Archaeocidaris nereis Müller, 1857, p. 262, Plate 4, figs. 11, 12a, 12b; Desor, 1858, p. 154, Plate 1, fig. 6;

Dujardin and Hupé, 1862, p. 465; Lovén, 1874, p. 43; Barrois, 1882, p. 321; Julien, 1896, p. 126,

Plate 6, figs. 6, 7; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris nereis Klem, 1904, p. 52.

Archaeocidaris protei Lambert and Thiéry, 1910, p. 124.

Known fragmentarily, interambulacral plates hexagonal, or pentagonal with rounded adradial border, primary tubercle pronounced, basal terrace marked; around the terrace on the outer portion of the scrobicular area, are numerous fine radial plications; minute secondary tubercles are outside of the scrobicular area. Primary spines cylindrical, vertically finely striate, and as Desor figures them, terminally with well developed spinules directed distally. Müller figures an excellent pyramid (my Plate 10, figs. 6, 7) which is wide-angled, indicating an inclined lantern, with moderately deep foramen magnum, and laterally with ridges for the

attachment of interpyramidal museles (p. 363). Müller's figures of interambulaeral plates are rather doubtfully referable to this species, but, as I show in *A. rossica*, plates differ enough in different parts of the test so that we must allow considerable latitude. Julien's figures are not recognizable, but his description appears to make his specimen referable to this species.

Lower Carboniferous, Regnitzlosau; Tournay, Belgium; Münster's eotypes of both *nerei* and *protei* are in the Munich Museum; Tournay, Belgium, British Museum Collection 32,847; Museum of Comparative Zoölogy Collection; La Varville and Sigaret (Julien); Assise de Lena; Villaneueva, Spain (Barrois). The references given to American localities by Desor and other European authorities are probably incorrect.

***Archaeocidaris rossica (Buch).**

Text-figs. 208, p. 184; 239 *bis*, p. 264; Plate 10, fig. 10; Plate 11, figs. 1-5; Plate 12, figs. 1-13k.

(?) *Cidaris deucalionis* Eichwald, 1841, p. 88. [Description is unrecognizable so the name cannot hold.]

Cidaris rossicus Buch, 1842, p. 323.

Cidarites rossicus Murchison, Verneuil and Keyserling, 1845, p. 17, Plate 1, figs. 2a-2c.

Palaeocidaris rossica L. Agassiz and Desor, 1846-'47, p. 367.

Echinocrinus rossica d'Orbigny, 1850, p. 154.

Palaeocidaris (Echinocrinus) rossica Vogt, 1854, p. 314.

Eocidaris rossica Desor, 1858, p. 156, Plate 21, figs. 3-6.

Echinocrinus deucalionis Eichwald, 1860, p. 652.

Eocidaris rossicus Geinitz, 1866, p. 61.

Archaeocidaris rossicus Trautschold, 1868, Plate 9, figs. 1-10b; 1879, p. 6, Plate 2, figs. 1a-1f, 1h, 1i, 1k, 1l; Quenstedt, 1875, p. 373, Plate 75, fig. 12; Klem, 1904, p. 55.

Archaeocidaris rossica Lovén, 1874, p. 43; Tornquist, 1896, text-fig. p. 27, Plate 4, figs. 1-5, 7, 8.

Archaeocidaris rossica var. *schellwieni* Tornquist, 1897, p. 781, Plate 22, fig. 12.

Cidarotropus rossica Lambert and Thiéry, 1910, p. 125.

This species is known from the most nearly complete material of any species of the genus; coming from the soft yellow calcareous clay beds of Moscow, the material is not distorted and is easily cleaned. Test compressed, spheroidal, about the form of a living eidarid. Ambulacral areas are narrow, sinuous, conforming to the outline of the adambulacral plates (Plate 10, fig. 10). Ambulacral plates are low, imbricating moderately ventrally and strongly beveled under the adambulacra (Plate 12, fig. 9). Pore-pairs are uniserial. There are four columns of plates in each interambulacral area. The plates at the mid-zone are higher than wide; ventrally they are not relatively so high, but dorsally are much higher than at the mid-zone; near the apical disc the young plates are very small, and smooth. The primary tubercles are strongly marked, scrobicular area large, basal terrace well developed at the mid-zone (Plate 11, fig. 4), and ventrally, but dorsally in the younger plates no terrace is developed. Passing dorsally to the still younger plates, it is seen (Plate 11, fig. 2) that the scrobicula is imperfectly developed,

then the tubercle is imperforate, and in the youngest plates, no primary tubercle exists. Secondary and very small miliary tubercles are thickly distributed along a narrow border outside the scrobicular circle, and dorsally this border is much larger on the aboral aspect of each plate. Primary spines are stout, inflated in the lower third, tapering from there distally; the milled ring is strongly marked, above which the spine is vertically finely striate for a short distance, and above this part densely studded with short blunt knob-like spinules, set without any definite order. Secondary spines 3 to 4 mm. long are situated on secondary tubercles on the borders of the plates; they are short, flattened, spathulate, vertically finely striate. Between the secondary spines are found some miliaries (Plate 11, fig. 4) which are minute and connected with miliary tubercles. These are the only miliary spines yet seen in the Palaeozoic. The peristome is plated with ambulacral, and many rounded strongly imbricate non-ambulacral plates. The lantern is typical of the Palaeozoic as described below.

Lower Carboniferous, Miatschkowa, Province of Moscow, Museum of Comparative Zoölogy; British Museum; Berlin Museum für Naturkunde, two specimens including the one described

by Tornquist (1896); Strassburg Museum; Munich Museum; Freiburg i. B. Museum. The var. *schellwieni* of Tornquist, Fusilinenkalk of the Carnic Alps; Miatschkowa and many other localities in Russia (Eichwald).

A very choice and complete test of this species is in the Munich Museum (text-fig. 239 bis; Plate 10, fig. 10; Plate 11, figs. 1, 2). This is the best preserved specimen known in the genus. On the peristome there are a few ambulacral and non-ambulacral plates all small and imbricating adorally. In the basicoronal row of the corona, in the interambulacra of areas A, I, G, the plates of columns 1 and 4 are whole and those of columns 3 and 2 are half plates, in which the ventral half has been re-

TEXT-FIG. 239 bis.—*Archaeocidaris rossica* (Buch). $\times 4$. Ventral border of corona and peristome, same specimen as Plate 11, fig. 1.

sorbed. On the other hand, in areas C and E, in the basicoronal row, the plates of columns 1 and 3 are half plates, of which the ventral half has been resorbed and the plates of columns 4 and 2 are whole. This, it is believed, as in *A. wortheni* (Plate 9, figs. 6–8) is associated with the introduction of columns in development. If, as in the figures cited, column 4 originates

to the right of the center, then in the adjustment of parts we find the arrangement of areas as in A, I and G in text-fig. 239 *bis*. Or if column 4 originates to the left of the center, we then have the arrangement as in areas C and E of text-fig. 239 *bis*. There are no gill slits (p. 223).

Passing dorsally up to the mid-zone, the hexagonal plates progressively increase in height relatively to their width and above the mid-zone this is still more marked. In the drawings of the Munich specimen the basal terrace is not brought out. My attention was not called to this feature when the drawings were made, but other specimens show it clearly on all plates up to the mid-zone, as in Plate 11, fig. 4. Above the mid-zone, however, in younger, though still large plates, the basal terrace is wanting. This is of much interest, as if such plates occurred alone as fossils, one would assume that the species had no basal terrace, and this probably accounts for the absence of a terrace as far as known in some species. Also, it is a condition like that of *Eocidaris* which as a genus (most imperfectly known) has no basal terrace. Desor referred *A. rossica* to *Eocidaris*, and he was probably misled by seeing only dorsal immature plates in which the terrace had not yet developed. Still further dorsally, as we pass into the area of really young plates, the scrobicule is first small and then wanting, the tubercle is imperfectly developed, then imperforate, and finally, in the younger plates, quite wanting, the plates close to the apical area being smooth without tubercles of any kind. This progressive development of characters of interambulacral plates as they grow older and are pushed ventrally, is exactly the same as may be traced in the development of fossil or Recent cidarids (Plate 3, figs. 1, 2) in some species of which it is especially marked (p. 106). In the *A. rossica* it is disappointing in such a perfect specimen not to have the oculars and genitals defined. There are many small plates in the center which are evidently periproctal; two of them lying above area D, and larger than the rest, may possibly be oculars or genitals (Plate 11, fig. 3).

Trautschold (1868) figured nearly complete lanterns in this species, but a specimen in the Munich Museum and some fine lanterns that Dr. E. O. Hovey kindly procured for me in Russia, now in the Museum of Comparative Zoölogy Collections, gave the opportunity to study details and to show somewhat better figures than Trautschold's. These are seen in text-fig. 208 (p. 184), and Plate 12, figs. 1-8. The lantern is depressed, subtending an angle of about 90 degrees. The pyramids are wide-angled, with curving sides which admitted of relatively long interpyramidal muscles. The foramen magnum is moderately deep. The teeth in place extend just above the base of the foramen magnum. The epiphyses are narrow, capping the half-pyramids, and present a glenoid cavity for interlocking with the condyles of the brace. The brace is block-shaped, as in Recent regular *Echini*. In one choice specimen (Plate 12, figs. 1, 2) a compass with bifid outer end is in place resting on the brace. This is the only good compass known in the Palaeozoic, though I also show one in *Pholidechinus brauni* and *Meekechinus elegans*. The sides of the pyramid are corrugated for the attachment of interpyramidal muscles. This lantern, as earlier discussed (pp. 81, 82), is very much like the lantern of young cidarids, also young *Strongylocentrotus*.

***Archaeocidaris agassizi Hall.**

Plate 13, figs. 1a-1e, 2-4.

Archaeocidaris agassizi Hall, 1858, p. 698, Plate 26, figs. 1a-1d; Lovén, 1874, p. 43; Quenstedt, 1875, p. 373, Plate 75, fig. 11; Keyes, 1894, p. 127, Plate 15, fig. 5; 1895, p. 185, Plate 18, fig. 5; Beede, 1900, p. 48, Plate 8, figs. 6-6e; Klem, 1904, p. 46; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris agassizii Jackson, 1896, p. 213.

A complete test is unknown, but specimens in Mr. F. Springer's collection add a good deal of information to that previously known. The ambulacra are narrow, plates low, beveled strongly under the adradials, pore-pairs uniserial. Interambulacrum with four columns of plates in an area; these plates are hexagonal, the height about equal to the width, basal terrace developed; many secondary tubercles are in a narrow row about the margin of plates. Primary spines are elongate, compressed, contracted above the milled ring, swollen in the lower third, and from there tapering to the tip, smooth proximally, above which muricate with small spinulose tubercles arranged quite definitely.

In Plate 13, fig. 4, are shown some ovally truncate plates which appear to be genitals. As they are not in place, nothing positive can be affirmed, but, while they do not resemble other known genitals in Echini, it is difficult to see what else they could be. The lantern is of the usual character, pyramids wide-angled, with moderately deep foramen, narrow epiphyses, and typical braces.

Burlington Limestone, Lower Carboniferous, Burlington, Iowa, American Museum of Natural History; Museum of Comparative Zoölogy Collection 3,034-3,038 and 3,191; F. Springer Collection; University of Michigan; Munich Museum; Hannibal, Missouri (Keyes); Upper Coal Measures, Topeka, Kansas (Beede).

Archaeocidaris illinoisensis Worthen and Miller.

Plate 13, fig. 5.

Archaeocidaris illinoisensis Worthen and Miller, 1883, p. 338, Plate 31, figs. 1a, 1b; Keyes, 1895, p. 187; Klem, 1904, p. 49; Lambert and Thiéry, 1910, p. 124.

Known fragmentarily. Primary spines stout, circular, swollen about the middle, studded with short sharp spinules that are directed outward and slightly distally. Rather close to *A. agassizi*, but the spines are not flattened and spinules are more pronounced as described.

Beach beds of St. Louis Limestone, Lower Carboniferous, near the Illinois Furnace, Hardin County, Illinois, holotype, no. 2,475, of the Illinois State Collection.

***Archaeocidaris coloradensis** nom. nov.

Plate 13, fig. 6.

Archaeocidaris ornatus Newberry, 1861, p. 116, Plate 1, figs. 2, 3, 3a; Keyes, 1895, p. 191; Klem, 1904, p. 54 (non *Echinocrinus* [*Archaeocidaris*] *ornatus* Eichwald, 1860, p. 654, Plate 32, fig. 24; non *Archaeocidaris ornatus* White, 1877, p. 104, Plate 6, fig. 7a, White's figure is here referred to *A. mucronata*, p. 271). *Archaeocidaris ornata* Lovén, 1874, p. 44; Lambert and Thiéry, 1910, p. 124.

Known only from fragmentary primary spines. These are 2.5 inches long by 0.36 of an inch in diameter, according to Newberry, but it may be remarked that his figured specimens are much shorter and very fragmentary. The spines are thickly studded with short spinules irregularly arranged, with points directed slightly distally. As Newberry's name *ornatus* is preoccupied by Eichwald's *ornatus* (see p. 274), I give a new name to the species.

Carboniferous (Coal Measures), Crinoidal Limestone, near junction of the two Colorados, and in same horizon, 60 miles west of that point, near Great Cañon of Colorado. Cotype (Plate 13, fig. 6), Columbia University Collection, no. 6,900 G.

***Archaeocidaris keokuk** Hall.

Plate 13, figs. 7a, 7b.

Archaeocidaris keokuk Hall, 1858, p. 699, Plate 26, figs. 2a, 2b; Keyes, 1894, p. 128; Klem, 1904, p. 50. *Archaeocidaris wortheni* Zittel, 1879, p. 485, text-fig. 343d (not 343a-343e, which are true *wortheni*). *Archaeocidaris keokuk* (*Heterocidaris*) Lambert and Thiéry, 1910, p. 124 (their page and plate references are to true *A. keokuk*, but this is not *Heterocidaris keokuk*, see Nomina Nuda).

Fragmentarily known. Interambulacral plates low, wide hexagons, basal terrace marked, scrobicule wide, secondary tubercles on narrow rim around the margin. Spines circular in section, of moderate length, muricate, with elongate ridges and spiniform tubercles.

Keokuk Limestone, Lower Carboniferous, Warsaw, Illinois, American Museum of Natural History; Clark County, Missouri; Boonville, Missouri (Klem).

***Archaeocidaris gracilis** Newberry.

Plate 13, fig. 8.

Archaeocidaris gracilis Newberry, 1861, p. 117, Plate 1, figs. 4, 4a; Klem, 1904, p. 49; Lambert and Thiéry, 1910, p. 124.

Fragmentarily known. Newberry says that the form of the interambulacral plates is unknown, but a fragment shows a single row of secondary tubercles around the scrobicule. Primary spines straight or curved, slender, tapering, circular in section, surface set with small spinules pointing distally.

For locality Newberry says, "Same as the last," which reads, Crinoidal Limestone [Coal Measures] near junction of the two Colorados, and in same rock, 60 miles west of that point, near the Great Cañon of the Colorado. The specimen figured (Plate 13, fig. 8), which is undoubtedly the original of Newberry's Plate 1, fig. 4, bears the locality label "Cañon Diamond River." It is in Columbia University Collection from the Newberry Collection.

****Archaeocidaris aculeata* Shumard and Swallow.**

Plate 13, figs. 9a-9f.

Archaeocidaris vcrneuilliana Swallow and Hawn, 1858, p. 180 (non King, 1850, description of Plate 6, figs. 22-24, for which see this memoir, p. 245).

Archaeocidaris aculeatus Shumard and Swallow, 1858, p. 223; Klem, 1904, p. 45; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris aculeata Miller, 1889, p. 225; Keyes, 1894, p. 130, Plate 15, fig. 3; 1895, p. 188, Plate 18, fig. 3.

Known only from dissociated spines and plates. Interambulacral plates are rather high hexagons, basal terrace marked, secondary tubercles in a narrow border on the margin of the plates. Primary spines are stout, inflated in lower third, circular in section or multiangular, with numerous fine short spinules directed distally. Primary spine 1 to 2 inches in length. The only published figure of the species is that by Keyes, but specimens kindly sent me by Dr. Beede are apparently this species and are so figured.

Upper Coal Measures, Valley of Verdigris River, on Santa Fé Road, near Rock Creek, and 25 miles west of Council Grove in valley of Cottonwood Creek; New Point, Jackson County, Missouri; Fort Belknap, Texas (Klem); Topeka, Kansas, Indiana University Collection. Miller (1889) and Miss Klem (1904) ascribe this species to the Permian in part.

****Archaeocidaris shumardana* Hall.**

Plate 13, figs. 10a-10c.

Archaeocidaris shumardana Hall, 1858, p. 699, Plate 26, figs. 3a-3d; Keyes, 1894, p. 128.

Archaeocidaris cf. *shumardana* Waleott, 1884, p. 313.

Archaeocidaris shumardiana Keyes, 1895, p. 186.

Archaeocidaris shumardina Keyes, 1895, p. 186.

Archaeocidaris shumardanus Klem, 1904, p. 56.

Archaeocidaris shumardi Lambert and Thiéry, 1910, p. 124.

Known only from plates and spines. Interambulacral plates are hexagonal, wider than high, basal terrace pronounced, secondary tubercles in a narrow row around the margins of the plates. Primary spines small, short, swollen in the lower third, smooth or finely striate proximally, above which muricate with elongate ascending spinules.

Warsaw Limestone, Lower Carboniferous, Warsaw, Illinois, American Museum of Natural History; Keokuk Limestone, LaGrange, Lewis County, Missouri. An *Archaeocidaris* sp. that approaches *shumardana*, Lower Carboniferous, Eureka District, Nevada (Walcott).

****Archaeocidaris edgarensis* Worthen and Miller.**

Plate 13, figs. 11a-11c, 12-14.

Archaeocidaris edgarensis Worthen and Miller, 1883, p. 337, Plate 30, figs. 15a-15c; Keyes, 1891, p. 245; Klem, 1904, p. 48; Lambert and Thiéry, 1910, p. 124.

Known only from dissociated plates, spines, and jaws. Interambulacral plates, as figured by Worthen and Miller, hexagonal, the height and width about equal. They do not show the basal terrace or serobicular area clearly; this is probably due to the wear of specimens. Primary spines long, tapering, slightly constricted above the milled ring, smooth proximally, above which thickly set with short spinules pointing distally. Portions of jaws associated with spines of this species are from Manhattan, Kansas. As seen in Plate 13, figs. 12-14, the pyramid is wide-angled, foramen magnum moderately deep, ridges exist laterally for the attachment of interpyramidal muscles. In an inner view (Plate 13, fig. 14) the dental slide is seen, but it does not reach the base of the foramen magnum, a general Palaeozoic character.

Upper Coal Measures, Carboniferous, near Baldwinville, Edgar County, Illinois. Type from this locality given as no. 2,447, in Illinois State Collection; Lower Coal Measures, Des Moines, Iowa; Junietta Group, Manhattan, Kansas, J. W. Beede Collection.

****Archaeocidaris newberryi* Hambach.**

Plate 8, fig. 9; Plate 13, figs. 15a, 15b.

Archaeocidaris newberryi Hambach, 1884, p. 551, Plate D, fig. 1; Keyes, 1894, p. 129; 1895, p. 187; Klem, 1904, p. 53; Lambert and Thiéry, 1910, p. 125.

Incompletely known. Ambulacral plates wide, low, with lateral bevel which would pass under the adradials as known in other species. Interambulacral plates hexagonal, wider than high, basal terrace marked, secondary tubercles with some small secondary spines in a narrow row along margin of plates. Primary spines very long up to or exceeding 57 mm. in length, slender, tapering throughout, with numerous fine sharp spinules pointing distally, and falling in definite parallel series.

Lower St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. The holotype from the Hambach Collection is now in Mr. F. Springer's collection, no. 8,119.

****Archaeocidaris tridifer* White.**

Plate 13, figs. 16a, 16b.

Archaeocidaris tridifer White, 1874, p. 17; 1876, p. 89; 1877, p. 104, Plate 6, figs. 8a, 8b; Keyes, 1895,

p. 191; Beede, 1900, p. 47, Plate 8, fig. 10; (?) Girty, 1903, p. 330; Klem, 1904, p. 59; Lambert and Thiéry, 1910, p. 125.

Archaeocidaris trudifera Miller, 1889, p. 225.

Known only fragmentarily. Interambulacral plates hexagonal, height and width about equal. Details of basal terrace, scrobicule, and secondary tubercles are not shown in the original figures. Primary spines long, fusiform, up to about 120 mm. long. Surface for a short distance above the milled ring apparently smooth, beyond which it is ornamented with numerous minute spinules arranged around the spine in imperfectly spiral lines.

Red Wall, Carboniferous (Coal Measures), Camp Apache, Navajo County, Arizona, cotypes in United States National Museum 8,471. Confluence of the Grand and Green Rivers, Utah; Topeka, Kansas; Leadville district, Colorado. Upper Coal Measures, Topeka Limestone, Topeka, Kansas (Beede).

****Archaeocidaris norwoodi* Hall.**

Plate 14, figs. 1a-1d.

Archaeocidaris norwoodi Hall, 1858, p. 701, Plate 26, figs. 5a-5e; Keyes, 1894, p. 129; 1895, p. 188; Klem, 1904, p. 54.

Cidarotropus norwoodi Lambert and Thiéry, 1910, p. 125.

Known only from dissociated plates and spines. Interambulacral plates are hexagonal, or pentagonal in adradial columns, wider than high, basal terrace marked. Scrobicular area sometimes shows obscure radiating plications, secondary tubercles in a narrow row on the margin of the plates. Primary spines are slender, elongate, slightly curving, longitudinally striate below and muricate above, with fine sharply elevated denticles, and at intervals marked by larger thorn-like diverging spinules; intermediate surface cancellate or granulose.

Kaskaskia Group, Lower Carboniferous, Chester, Illinois, American Museum of Natural History; Kaskaskia, Illinois; near St. Louis, Missouri (Klem).

***Archaeocidaris paradoxa* (Eichwald).**

Plate 14, fig. 2.

Palaeocchinus paradoxus Eichwald, 1856, p. 127; 1860, p. 650, Plate 32, fig. 25 (but not fig. 26).

Palaeocchinus paradoxus Stueckenberg, 1898, pp. 230, 343; Klem, 1904, p. 35; (?) Lambert and Thiéry, 1910, p. 119.

The spine, which is the only recognizable part of Eichwald's figures or description, evidently belongs to an *Archaeocidaris*. The shaft only is known, which is stout, tapering gradually, with frequent irregularly placed, stout, thorn-like spinules directed distally. What Eichwald figured as a test (his Plate 32, fig. 26) is an unrecognizable mass, but is entirely the wrong shape for an *Archaeocidaris*. It evidently has no relation to the spine.

Upper Carboniferous (Coal Measures), Sterlitamak and Saraninsk, Ural, Russia.

***Archaeocidaris mucronata** Meek and Worthen.

Plate 14, figs. 3a, 3b, 4.

Archaeocidaris mucronatus Meek and Worthen, 1860, p. 395; 1866, p. 295, Plate 23, figs. 3a-3c; Klem, 1904, p. 52.

Archaeocidaris ornatus White, 1877, p. 104, Plate 6, fig. 7a (non *Echinocrius* [*Archaeocidaris*] *ornatus* Eichwald, 1860, for which see p. 274; non *Archaeocidaris ornatus* Newberry, 1861; non *Archaeocidaris ornata* Lambert and Thiéry, 1910, p. 124, for which see p. 267).

Archaeocidaris mucronata Keyes, 1895, p. 188; Lambert and Thiéry, 1910, p. 124.

Known only from dissociated plates and spines. Interambulacral plates hexagonal, wider than high, width 0.5 of an inch, height 0.35 of an inch. Primary spines long, tapering, slightly compressed, or nearly circular in section, and apparently a little curved near the base, smooth proximally, beyond which they are armed with strong, sharp lateral spinules directed obliquely distally. Length of a primary spine 2.6 inches, greatest diameter of shaft 0.16 of an inch.

Chester Group, Lower Carboniferous, Liberty, Randolph County, and Chester, Illinois. The spine figured by Dr. White (1877) as *ornatus* is apparently referable to this species and is from the Carboniferous (Coal Measures) of Ojo del Oso, near Fort Wingate, New Mexico; this specimen is in the United States National Museum Collection 8,472.

***Archaeocidaris dininnii** White.

Plate 14, figs. 5a-5b.

Archaeocidaris diuinii White, 1880, p. 260, Plate 1, figs. 13-15; 1880a, p. 131, Plate 35, figs. 6a-6c;

Keyes, 1894, p. 130, Plate 15, figs. 6a-6c; 1895, p. 190, Plate 18, figs. 6a-6c.

Archaeocidaris diuinii Klem, 1904, p. 48; Lambert and Thiéry, 1910, p. 125.

Known only from primary spines which are fusiform, 50 to 60 mm. long, with a greatest diameter of about 5 mm. Above the short plain neck the whole spine is studded with many irregularly disposed spinules, 1 to 2 mm. long, which stand out nearly at right angles to the shaft, except near its apex, where they are directed distally. The spinules are usually more numerous and stronger upon the lower portion of the spines, and upon the middle portion of some of them the spinules are obsolete. The smaller spines are usually more slender or less fusiform than the larger. A striking feature of this species is that the spinules are directed at right angles to the shaft.

Upper Coal Measures, near Tecumseh, Nebraska, eotype in United States National Museum Collection 8,031. Upper Coal Measures, Kansas City, Missouri; Red Oak, Iowa (Klem).

****Archaeocidaris cratis* White.**

Plate 14, fig. 6.

Archaeocidaris cratis White, 1876, p. 109; 1880, p. 130, Plate 33, fig. 2a; Keyes, 1895, p. 188; Girty, 1903, p. 331; 1908, p. 110; Klem, 1904, p. 47; Lambert and Thiéry, 1910, p. 125.

Archaeocidaris sp. a, Girty, 1908, p. 110.

Known only from primary spines, which are slender, tapering, terete, shaft with sharp, distinct, distant spinules, each about 1.5 mm. long and pointing distally. Length of spine about 60 mm., diameter just above milled ring about 4 mm. Differs from *mucronata* in that the spine is more slender, terete, and spinules more widely and irregularly distributed.

Girty's (1908) species "a" may well be considered an immature spine of an adult, or the spine of a young individual of *cratis*.

Carboniferous (Coal Measures) at confluence of the Grand and Green Rivers, Utah, holotype from this locality in United States National Museum Collection 8,235; Nebraska. Crested Butte district; Leadville district and Ouray, Colorado (Girty). Guadalupe Point, Guadalupe Mountains, Texas (Girty).

***Archaeocidaris acanthifera* Trautschold.**

Plate 14, figs. 7, 8a, 8b.

Archaeocidaris acanthifera Trautschold, 1879, p. 7, Plate 2, fig. 1u [no number on figure on the Plate].

Archaeocidaris sp. Hind, 1905, p. 529, Plate 25, figs. 1, 1a.

Known only from primary spines, which are slender, tapering, with long irregularly placed spinules pointing moderately distally. The specimens figured by Hind appear referable to this species, although the spinules are not so long as in the type. These specimens are from the Coal Measures of Staffordshire, England, and are apparently the only Palaeozoic Echini yet recorded in Europe from the Coal Measures.

Lower Carboniferous, Miatschkowa, Province of Moscow, Russia (Trautschold). Coal Measures, Nettlebank, Staffordshire, England.

***Archaeocidaris pizzulana* Gortani.**

Plate 10, figs. 12a-12d.

Archaeocidaris pizzulana Gortani, 1905, p. 586, Plate 15, figs. 29-33, 36f.

Cidarotropus pizzulana Lambert and Thiéry, 1910, p. 125.

Known from dissociated interambulacral plates and spines. Interambulacral plates are hexagonal, wider than high, with a double ring of secondary tubercles on the margin. Primary spines smooth, cylindrical, with from three to six pairs of opposite spinules. The spinules are stout, thorn-like, and directed distally. This species is the only Palaeozoic echinoid so far known from Italy.

Frequent in the calcareous schists, Carboniferous, Forca Pizzul, Carnic Alps.

***Archaeocidaris megastyla** Shumard and Swallow.

Plate 14, fig. 13.

Archaeocidaris megastylus Shumard and Swallow, 1858, p. 225; Keyes, 1894, p. 129, Plate 15, figs. 2a, 2b;

1895, p. 189, Plate 18, figs. 2a, 2b; Beede, 1900, p. 49, Plate 8, fig. 7; Klem, 1904, p. 51.

Archaeocidaris megastylis Lovén, 1874, p. 44.*Cidarotropus megastylus* Lambert and Thiéry, 1910, p. 125.

Known incompletely from plates and spines. Interambulacral plates are large, hexagonal, wider than high, rather thick; scrobicular area very broad, nearly circular; primary tubercle very large, and relatively large secondaries are in a narrow row on margin of plates. Primary spines long, robust, circular in section, length about 3 inches. In the original description Shumard and Swallow say the spine is studded with rather distant granules, or minute short spines. Keyes's interpretation of the species is spines with rather large spinules of which he gives a good figure. As Shumard and Swallow published no figure and their specimens may have been worn, I accept Keyes's version and consider the spinules as relatively large. This character is shown well in a specimen in the United States National Museum which I figure and which in other respects appears referable to this species.

Upper Coal Measures, near headwaters of Verdigris River, and in the Valley of Cottonwood Creek, Kansas; Independence, Jackson County, Missouri; St. Louis Group, St. Louis, Missouri, United States National Museum Collection 43,009, from E. O. Ulrich Collection (Plate 14, fig. 13); Kansas City (Beede).

***Archaeocidaris biangulata** Shumard and Swallow.

Plate 14, figs. 9a-9d.

Archaeocidaris biangulatus Shumard and Swallow, 1858, p. 224; Klem, 1904, p. 47.*Archaeocidaris biangulata* Lovén, 1874, p. 44; Keyes, 1894, p. 130, Plate 15, figs. 1a-1c; 1895, p. 189,

Plate 18, figs. 1a-1c.

Cidarotropus biangulata Lambert and Thiéry, 1910, p. 125.

Known from dissociated plates and spines. Interambulacral plates hexagonal, wider than high, basal terrace marked, secondary tubercles in a narrow row on the margin of the plates. Shumard and Swallow say areolar surface with radial striae; but such are not visible in specimens I have seen. Primary spines are very striking in character. They are smooth for a slight distance above the milled ring; the shaft is terete throughout, but is ornamented with two strongly marked, opposite, wing-like expansions which are in part at least nearly entire in outline, or serrately spinose. Distally the flanges pass into the general spinulose character of the shaft. Aside from the flanges, the shaft is nearly smooth at least proximally, but distally the whole of the shaft is thickly set with relatively long, pointed spinules closely resembling

those of the whole spine in *mucronata*. Shumard and Swallow say the length of primary spines is about 2.5 inches, diameter including spinules 0.1 of an inch.

Middle Coal Measures, Lexington, Missouri; Kansas City, Missouri. Huerco Formation, Diablo Mountains, western Texas, United States National Museum Collection.

***Archaeocidaris ornata* (Eichwald).**

Plate 14, fig. 10.

Echinocrinus ornatus Eichwald, 1860, p. 654, Plate 32, fig. 24 (non *Archaeocidaris ornatus* Newberry, 1861, for which see *A. coloradensis*, p. 267; non White, 1877, for which see *A. mucronata*, p. 271; non Klem, 1904, p. 54; non Lambert and Thiéry, 1910, p. 124, for which see p. 267).

Known only from primary spines. Milled ring well developed, above which the shaft tapers to the distal end; the spine is smooth proximally, but distally thickly set with long spinules directed distally at an acute angle.

Lower Carboniferous, Miatschkowa, near Moscow, Russia.

****Archaeocidaris ourayensis* Girty.**

Plate 14, fig. 11.

Archaeocidaris ourayensis Girty, 1903, p. 329, Plate 1, fig. 14; Klem, 1904, p. 63; Lambert and Thiéry, 1910, p. 125.

Known only from a primary spine, which has a slender axis slightly over 1 mm. in diameter, densely clothed with relatively large and stout spinules directed distally. Base and tip of spine unknown.

Hermosa Formation, Carboniferous (Coal Measures), Ouray, Colorado, holotype, United States National Museum Collection 35,369.

****Archaeocidaris triplex* White.**

Plate 14, figs. 12a-12c.

Archaeocidaris triplex White, 1881, p. xxii, Plate 4, figs. 3a-3c; (?) Girty, 1903, p. 330; Klem, 1904, p. 57; Lambert and Thiéry, 1910, p. 125.

Practically known only from interambulacral plates and primary spines. Interambulacral plates described by Dr. White as imperfect, small, thin, only probably belonging to the same species as the spines. Primary spines large, strong, subtriangular in cross section; spinules are strong, short, but prominent and rather distant, in three rows, each upon one of the three obtuse angles of the spine. The rows of spinules extend from a little way above the milled ring to the end of the spine; the rest of the surface is smooth.

Carboniferous (Coal Measures), near Taos, New Mexico, cotypes, United States National Museum 9,449; (?) San Juan region, Needle Mountains, Colorado.

***Archaeocidaris triserialis (M'Coy).**

Plate 8, fig. 10; Plate 14, fig. 14.

Echinocrinus triserialis M'Coy, 1844, p. 173, Plate 26, fig. 1 (on the legend of Plate 26, fig. 1, the printed generic name has been erased and *Echinocrinus* written in pencil; see footnotes, pp. 275, 277, 280).

Archaeocidaris triserialis Desor, 1858, p. 155; M'Coy, 1862 (on legend of Plate 26, fig. 1)¹; Klem, 1904, p. 58; Lambert and Thiéry, 1910, p. 125.

Known only from primary spines, which are triangular in section, each of the three angular ridges armed with a row of strong tooth-like spinules; intervening space smooth; the sides between the angles are flat and almost equal. Length of specimen that M'Coy figured is one inch eight lines, diameter one and a half lines; but it was incomplete at each end.

Arenaceous Limestone, Lower Carboniferous, Killycloghy, Lisbellow, County Tyrone, Ireland. Holotype and only recorded specimen in the Science and Arts Museum, Dublin. Dr. Scharff kindly sent me the photograph of this specimen which is here reproduced.

***Archaeocidaris triserrata Meek.**

Plate 14, figs. 15a-15c.

Archaeocidaris (?) *triserrata* Meek, 1872, p. 151, Plate 1, figs. 6a-6c.

Archaeocidaris triserrata Miller, 1889, p. 225.

Archaeocidaris triserrata Keyes, 1895, p. 190.

Archaeocidaris triserratus Klem, 1904, p. 58; Lambert and Thiéry, 1910, p. 125.

Known only from primary spines, which are moderately long, rather slender and usually a little arched near the base, where they are nearly or quite circular in section. Farther up they are compressed, rhombic in section, the lateral margins being sharp and regularly serrated, the little tooth-like projections inclined outward, and toward the apex of the spine. There are probably from 25 to 30 serrations on each side of the spine and from 9 to 12 of them may be counted in the space of half an inch. On the middle of one face of the spine there is a third serrated carina extending about two thirds the length of the spine; on the other face three or four rows of smaller granules or elongate nodes extend from the shank of the spine, but become obsolete near the middle. Length about 2.30 inches. No entire specimens were found.

Upper Coal Measures, near Omaha, Nebraska, cotypes in United States National Museum Collection 6,599; Platte River, Nebraska; Vermilion County, Illinois; Kansas City, Missouri.

¹ While *Archaeocidaris triserialis* is printed on the Plate as stated, Dr. Kitchin writes me that M'Coy (1862, p. 274) in the list of errata says "Plate 26, fig. 1, read *Echinocrinus* instead of *Archaeocidaris*. (See footnotes pp. 277, 280.)

Archaeocidaris rankini Young.

Archaeocidaris rankini Young, 1882, p. 108.

Known only from primary spines which bear four rows of spinules or denticles; these are long, thorn-like, and stand out from the shaft at nearly a right angle. This is the only species in which there are four rows of spinules described. No figure has been published.

Lower Carboniferous shales, Gillfoot, Carlisle, Scotland.

Archaeocidaris prisca (Münster).

Cidarites priscus Münster, 1839, p. 41.

Echinocrinus priscus L. Agassiz, 1841, p. 16.

Palaeocidaris prisca L. Agassiz and Desor, 1846-'47, p. 340.

Echinocrinus prisca d'Orbigny, 1850, p. 154.

Archaeocidaris prisca Desor, 1858, p. 154.

Archaeocidaris priscus Klem, 1904, p. 63; Lambert and Thiéry, 1910, pp. 124, 125.

Known only from individual plates and spines. Tubercles sensibly larger than in *A. nerei*. Primary spines with six granular ridges. No figure has been published.

Carboniferous, Regnitzlosau, Belgium.

Archaeocidaris wervekei Tornquist.

Plate 14, figs. 17a-17f.

Archaeocidaris wervekei Tornquist, 1897, p. 778, Plate 21, fig. 4; Plate 22, figs. 1, 2, 3, 9, 10; (?) Fraipont, 1904, p. 11, Plate 1, figs. 6, 7.

Archaeocidaris wervekei Lambert and Thiéry, 1910, p. 125.

Interambulacral plates are hexagonal, or pentagonal in adradial columns, very high, the height equaling or exceeding the width, basal terrace marked, strong radial plications extending from margins of plates inward. Primary tubercles exceptionally high. Primary spines are incomplete, vertically plicate and finely striate. Nodose eminences are on the ridges between plications. Dr. Tornquist gives a striking and very satisfactory restoration, representing a complete test in side view. In it he shows narrow ambulacral areas, and four columns of plates in the interambulacral areas. The whole test is represented as depressed spheroidal, and I believe is quite correct in form.

Fusilina Limestone, Lower Carboniferous, Hunsrück, Alsace, Germany; Lower Carboniferous, Marbre Noir de Dinant, Belgium (Fraipont).

***Archaeocidaris urii** (Fleming).

Plate 14, figs. 16, 18, 19a-19c, 20a-20c; Plate 15, figs. 1, 2a-2c, 3.

Echinus ——— Ure, 1793, p. 318, Plate 16, figs. 7, 8.

Cidaris urii Fleming, 1828, p. 478; M'Coy, 1862, (in legend of) Plate 27, fig. 1 (see footnote p. 277).

Cidaris vetusta Phillips, 1836, p. 208; Portlock, 1843, pp. xxvi, 353, Plate 16, fig. 11.

Echinocrinus urii L. Agassiz, 1841, p. 16; M'Coy, 1844, p. 174, Plate 27, fig. 1 (the generic name on legend of plate in pencil).¹

Cidaris benburbensis Portlock, 1843, pp. xxvi, 352, Plate 16, figs. 10a-10d.

Echinocrinus vetustus M'Coy, 1844, p. 174.

Archaeocidaris urii Roemer, 1852-'54, p. 288, Plate 4, fig. 2; Desor, 1858, p. 154, Plate 21, figs. 11, 12; Baily, 1875, p. lxxviii, Plate 36, figs. 12a, 12b; Keeping, 1876, p. 39, Plate 3, figs. 14-18; Julien, 1896, p. 123, Plate 16, figs. 8-10; Tornquist, 1897, p. 775, Plate 22, figs. 4-7, 11; Fraipont, 1904, p. 11, Plate 1, fig. 5; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris vetusta Dujardin and Hupé, 1862, p. 466; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris [urii] Young, 1873; 1876.

Archaeocidaris urci Lovén, 1874, p. 43; Neilson, 1895, p. 77, text-fig. 3; Klem, 1904, p. 59.

Archaeocidaris benburbensis Etheridge, 1888, p. 221.

Archaeocidaris gruneri Julien, 1896, p. 125, Plate 16, figs. 11, 12; Klem, 1904, p. 62; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris regimontana Parkinson, 1903, p. 365, Plate 15, fig. 13; Lambert and Thiéry, 1910, p. 124.

Archaeocidaris vetustus Klem, 1904, p. 61.

This species is widely distributed and represented by some very good material. The most complete portion of a test known to me is from Knock Hill Quarry, Fife, Scotland, and is in the Museum of Practical Geology, London. In this specimen (Plate 15, fig. 1) the ambulacrum is narrow, 5.5 mm. in width. The ambulacral plates are low with pore-pairs uniserial. In one area of this specimen it is seen that there are four columns of interambulacral plates, the same number that is found in all other species of the genus where a complete area is known. The interambulacral plates of median columns are low, wide hexagons, and those of adradial columns are pentagonal with a strongly rounded line on the adradial suture. This specimen shows that there are four plates in the basicoronal row of the interambulacrum and also traces of ambulacral and non-ambulacral plates on the peristome (compare Plate 9, figs. 6, 7). The largest interambulacral plate measured is 12 mm. in width by 6.5 mm. in height. The surface characters of the plates are not shown well in this specimen, though they are in others from the same locality. In another specimen from this locality in the Jermyn St. Museum, an interambulacral plate measures 13 mm. in width by 9 mm. in height. It also shows primary spines of the usual size and character in the species.

¹ In a copy of M'Coy's Carboniferous Limestone Fossils of Ireland, of the 1862 edition, seen at the Jermyn St. Museum, London, the name *Cidaris urii* is printed on the plate as stated (p. 276). In two copies of the 1844 edition, which was privately issued by Sir Richard Griffith, one at the British Museum, and one at the Museum of Comparative Zoölogy, the generic name is erased on the plate and changed in pencil to read *Echinocrinus urii*. Dr. Bather (1907, p. 453, footnote) says of M'Coy's publication, "In the legend to the lithographed plates the name *Archaeocidaris*, which had been printed, was erased, and the name *Echinocrinus* inserted by hand." According to the evidence Dr. Bather is mistaken, and the name erased was doubtless *Cidaris*, not *Archaeocidaris*. (See footnotes, pp. 275, 280.)

The imbrication of plates in this species was described by Professor Young, who, I believe was the first to show that this character occurred in *Archaeocidaris*.

A specimen from Fermanagh, North Ireland, in the Jermyn St. Museum, no. 7,659 (Plate 14, figs. 20a-c), shows interambulacral plates with prominent tubercle, basal terrace, secondary tubercles, and strong radial plications which extend inward from the margins of the plate; also a characteristic primary spine with its strong spinules extending distally from elevated ridges. The longest spine measures 64 mm. in length, is longitudinally finely striate and thickly set with spinules. This specimen is of importance as it is the original holotype of Portlock's *Cidaris benburbensis* from whose figures mine are taken. Portlock (1843, p. 353) gives the locality as Benburb, boundary of Armagh and Tyrone. This may be the correct locality of this type; but Fermanagh is the locality given on the old original label in the Jermyn St. Museum. Dr. Kitchin tells me that the matter of the locality for this specimen is open to question. Portlock may have been mistaken, or some error may have crept into the label before the day of catalogues.

A fine specimen from Millstone Neuk, Dunbar, Scotland, in the Jermyn St. Museum, is of interest from the very perfect condition of preservation of the spines. The longest of these, which is not quite complete distally, measures 61 mm. in length. The spinules are beautifully preserved, measure about 1.5 mm. in length, and are set at an angle of about 45° from the axis of the shaft, pointing distally.

A specimen from Corwen, Wales, in the Sedgwick Museum, Cambridge, England, shows the surface characters of interambulacral plates very clearly, as figured by Keeping, from whom my figures (Plate 14, figs. 19 a-c) are taken. Of these plates, several show the basal terrace and radial plications extending inward from the margins. A peculiar elongate plate occurs in this specimen (Plate 14, fig. 19c), the nature of which is doubtful. As it has a perforation near one end, it is possibly a genital plate, but genitals are so far not definitely known in the genus (pp. 265, 266, 414).

The species *Cidaris vetusta* Phillips, as suggested by M'Coy (1844), may be reasonably referred to *urii* as a synonym. Phillips described the spines as rudely muricate, and Portlock described them as having four or more rows of strong prickles. A specimen from the Portlock Collection, from Fermanagh, Ireland, in the Jermyn St. Museum, no. 16,321, bears the old manuscript label *Cidaris vetusta*. It is doubtless the specimen referred to by Portlock (1843, p. 353) from this locality, but is not the original of his Plate 16, fig. 11. The spines and plates of this specimen are not distinguishable from *urii*, though in the plates the radial plications are only faintly preserved. Another specimen from the Portlock Collection, from Clogher, County Tyrone, Ireland, in the Jermyn St. Museum, no. 7,768, consists of two interambulacral plates on a slab with other fossils. This specimen is probably the one referred to by Portlock (1843, p. 353) from this locality, and one of the plates corresponds so closely with that figured by

Portlock in his Plate 16, fig. 11 (here reproduced as Plate 14, fig. 16) that it is probably the original of this figure. This plate is hexagonal, measures 11 mm. in width by 10 mm. in height; has a prominent primary tubercle, basal terrace, and on the border a row of secondary tubercles as figured by Portlock. This is the only published figure ascribed to the species *vetusta*.

Julien's *A. gruneri* is in all probability simply based on small and probably young specimens. It presents no specific differences. *A. regimontana* Parkinson is also doubtless a synonym.

Lower Carboniferous, Fermanagh, North Ireland, Museum of Practical Geology, no. 7,659 (the holotype of Portlock's *Cidaritis benburbensis*. See note above in regard to the locality of this specimen); Benburb, Ireland, Trinity College, Dublin; Knock Hill Quarry, Fife, Scotland, Museum of Practical Geology, nos. 16,316 to 16,319; Millstone Neuk, Dunbar, Scotland, Museum of Practical Geology 25,507, 25,508; Fermanagh, Ireland, no. 16,321, and Clogher, County Tyrone, Ireland, no. 7,768, Museum of Practical Geology; Hayfod-y-Caleh, Corwen, Wales, Sedgwick Museum, Cambridge; Yorkshire, Museum of Comparative Zoölogy Collection 3,062; near Glasgow, Museum of Comparative Zoölogy Collection; Bristol, British Museum Collection 75,724; Bunderan; Ballantillich, Rahan's Bay, Ireland, and Derbyshire, England, Sedgwick Museum, Cambridge, England; Craigenglen, Campsie, Scotland (Young); Calderwood Limestone, in neighborhood of East Kilbride, Scotland (Neilson); Ardisière, France (Julien); Hunsrück, Alsace, Germany (Tornquist); Culm, Königsberg (Parkinson's *A. regimontana*); Marbre Noir, Dinant, Belgium (Fraipont); Phillips (1836) gives as localities for his *Cidaritis vetusta*, here considered a synonym, Ravenstonedale; Whitewell, Northumberland; Coalbrookdale and Florence Court.

Archaeocidaritis halliana (Geinitz).

Plate 15, figs. 4a-4c.

Eocidaritis hallianus Geinitz, 1866, p. 61, Plate 5, figs. 1a, 1b, 2a, 2b; Meek, 1872, p. 152, Plate 7, figs. 9a-9d; Klem, 1904, p. 68.

Eocidaritis hallanus Miller, 1889, p. 242.

Archaeocidaritis hallianus Keyes, 1894, p. 129; 1895, p. 190.

(?) *Eocidaritis halliana* Girty, 1903, p. 332.

Cidarotropus hallianus Lambert and Thiéry, 1910, p. 125.

Known only from isolated interambulacral plates and primary spines. Plates hexagonal, wider than high, with basal terrace, as figured by Geinitz, large secondary tubercles in a single row well in from the margin of the plate, and numerous minute granules on the marginal area. Plates small, up to 3 mm., as given by Geinitz. Primary spine slender, terete, tapering from the milled ring to the tip. Vertically finely striate, the elevated ridges being minutely and regularly set with granules. Spines about 7 mm. long.

Upper Coal Measures, Nebraska City, Nebraska; Kansas City, Missouri; (?) Leadville district and Crested Butte district, Colorado.

***Archaeocidaris muensteriana** (Koninck).

Plate 15, figs. 5a-5c.

Cidaris muensterianus Koninck, 1842-'44, p. 35, Plate E, figs. 2a-2d.*Cidarites munsterianus* Koninck, 1842-'44, [description of] Plate E.*Echinoerinus munsterianus* (?) M'Coy, 1844, p. 173, Plate 27, fig. 2 (name on legend of plate in pencil).¹*Cidaris münsteriana* L. Agassiz and Desor, 1846-'47, p. 367.*Eocidaris munsterianus* Desor, 1858, p. 156.*Cidaris elegans* M'Coy, 1862, [on legend of] Plate 27.¹*Lepidocentrus münsterianus* Koninck, 1869, p. 546; 1870, p. 260; (non Julien, 1874, p. 76, for which see *Pholidocidaris gaudryi*).*Archaeocidaris münsteriana* Lovén, 1874, p. 43; Young, 1876, p. 230.*Archaeocidaris elegans* Etheridge, 1888, p. 221.*Archaeocidaris münsterianus* Etheridge, 1888, p. 221.*Eocidaris münsterianus* Klem, 1904, p. 69.*Eocidaris munsteri* Lambert and Thiéry, 1910, p. 126.

Known only from primary spines and incomplete interambulacral plates. Interambulacral plates of doubtful outline, probably hexagonal, primary tubercle with large serotubercular area; a basal terrace is not figured, but it is quite likely worn off. Primary spines spindle-shaped, with numerous vertical denticulate ribs, arranged regularly in parallel series.

Lower Carboniferous, Visé, Belgium; Ireland; Beith district, Ayrshire in Scotland (Young); Visé, and Tournai, Belgium, British Museum Collection 32,846 and 56,991.

Archaeocidaris forbesiana (Koninck).

Plate 15, figs. 6a-6c.

Cidaris forbesiana Koninck, 1863, p. 574, Plate 4, figs. 1, 2; 1863a, p. 4, Plate 4, figs. 1-2a.*Eocidaris forbesiana* Waagen, 1879-'87, p. 819, Plate 95, figs. 5-16.*Permocidaris forbesiana* Lambert, 1899a, pp. 39, 47.*Eocidaris forbesianus* Klem, 1904, p. 67.*Permocidaris forbesi* Lambert and Thiéry, 1910, p. 127.

This species is known from isolated interambulacral plates and spines. The plates are most imperfectly known, and the figures given by Waagen seem to be of quite impossible shapes as regards outline, also the primary tubercle is so peculiar that it differs from that of any known type. With the meager knowledge and doubtful character of the material, it seems to me best to place it in *Archaeocidaris* rather than make it the basis of a distinct generic type, as does Lambert. The primary spines on which the species was based by de Koninck, are large,

¹ In a copy of M'Coy's Carboniferous Fossils of Ireland of the 1862 edition, seen at the Jermyn St. Museum, the name *Cidaris elegans* is printed on the plate as stated. In two copies of the 1844 edition, one at the British Museum, and one at the Museum of Comparative Zoölogy, the name on the plate is erased and changed in pencil to read *Echinocrinus munsterianus* (see footnotes pp. 275, 277).

stout, and strongly swollen in the middle. The milled ring is weakly defined, shaft smooth for about the lower third, above which it is ornamented with numerous elevated nodose spinules arranged in quite definite parallel series, of which, judging from the figures, there must be about 14 vertical series on a spine.

Productus Limestone, Permian, Katta, Golawali, Chidru, and Bazarwan, India.

***Archaeocidaris spinoclavata* Worthen and Miller.**

Plate 15, figs. 7a-7h.

Archaeocidaris (?) *sp. undet.* Meek and Worthen, 1873, Plate 24, figs. 13a-13c.

Archaeocidaris spinoclavatus Worthen and Miller, 1883, p. 327, Plate 30, figs. 14a-14c; Keyes, 1895, p. 190; Klem, 1904, p. 57.

Archaeocidaris spinoclavata Miller, 1889, p. 225; Lambert and Thiéry, 1910, p. 124.

Known only from dissociated interambulacral plates and primary spines. Interambulacral plates hexagonal, wider than high, with a nodose rim around the margin, the expression of secondary tubercles. The basal terrace is not shown, and the details of the surface are doubtful in Worthen and Miller's figures, but, as they say, the specimens are highly silicified and external markings thereby obscured. Primary spines long, or short, circular in section, contracted above the milled ring, beyond which very soon, or at a considerable distance, the spine expands to a marked degree. If it expands quickly, the spine appears highly swollen, as in Plate 15, figs. 7g, 7h, or this may be much less marked, as in fig. 7f, or the greatest expansion may be near the tip of the spine, as in fig. 7e. Proximally the spine is smooth for a short distance, above which it is thickly clothed with nodose spinules. This species is more variable in the form of the spines than other species of the genus yet known.

Middle and Lower Coal Measures, St. Clair and Marshall Counties, Illinois. Cotypes are stated as in the Illinois State Collection 2,404.

***Archaeocidaris sp. b.* Girty.**

Archaeocidaris sp. b. Girty, 1908, p. 110, Plate 27, figs. 18, 18a.

Archaeocidaris sp. b. var. The same, p. 111.

Archaeocidaris sp. c. The same, p. 111.

Archaeocidaris sp. d. The same, p. 111.

Most fragmentary, based on two pieces of spines which Girty thinks resemble *A. spinoclavata*, and yet are different, so I insert the record at this place pending further knowledge, should such be attained. The piece representing the distal end expands rapidly into an almost knob-like tip, which, with the shaft, Girty says, appears to be ornamented with short spinules. The shaft is about 0.75 mm., and the expanded distal tip about 2 mm. in diameter. To recognize a varietal form of a species which itself is so shadowy that Girty gives it no name, does seem

beyond all reason in splitting. Certainly, without injustice to Girty, his variety of *b* and his species *c* and *d* may reasonably be left under his species *b*, until better material turns up.

Delaware Mountain Formation, Carboniferous (Coal Measures), southern Delaware Mountains, Texas; and Dark Limestone, Pine Spring, Guadalupe Mountains, Texas.

***Archaeocidaris clavata* (Eichwald).**

Plate 15, fig. 8.

Echinocrinus clavatus Eichwald, 1860, p. 653, Plate 23, fig. 16.

Known only from primary spines, which are club-shaped, above the milled ring expanding to the thickest part, which is near the distal apex, tapering to a blunt end; with marked, sinuous, fluted ridges unlike other known species.

Carboniferous, Yegorjefsk, in the Province of Kalonga, Russia.

LEPIDOCIDARIS Meek and Worthen.

Lepidocidaris Meek and Worthen, 1873, p. 482; Lovén, 1874, p. 44; Duncan, 1889a, p. 12; Lambert and Thiéry, 1910, p. 126.

This genus differs very markedly from *Archaeocidaris*, and instead of having many species, as in that genus, there is at present only one species known. The test is high, spheroidal, or perhaps spherical. Ambulacral areas narrow, with two columns of low plates. Ambulacral plates not all alike, but at the mid-zone every third plate is higher and wider than the two intermediate and more or less completely abutting against the two smaller plates of the opposite half-area (Plate 17, figs. 2, 3, 12). Interambulacra are wide, with from six to eight columns of large hexagonal plates, or pentagonal in adradial columns. The plates are high, rounded, imbricating moderately aborally, and from the center laterally, and over the ambulacrals. Each interambulacral plate has a large perforate primary tubercle with a deep sunken, rather small scrobicular area but no basal terrace. On the high rounded area beyond the scrobicular circle, the surface bears many small secondary tubercles. Spines are long, cylindrical; primary spines are associated with the primary tubercles and minute secondary spines with the secondary tubercles. Oculars and genitals unknown. A typical Palaeozoic inclined lantern exists.

Type and only known species *L. squamosa* of the Lower Carboniferous.

****Lepidocidaris squamosa* Meek and Worthen.**

Plate 16, figs. 1-3; Plate 17, figs. 1-14.

Eocidaris (?) *squamosa* Meek and Worthen, 1869, p. 79.

Eocidaris (?) *squamosus* Meek and Worthen, 1873, p. 478, Plate 9, figs. 15a-15g.

Lepidocidaris squamosus Meek and Worthen, 1873, p. 478; Jackson, 1896, p. 220, Plate 7, fig. 41; Klem, 1904, p. 72.

Lepidechinus squamosus Keyes, 1895, p. 193.

Lepidocidaris squamosus Lambert and Thiéry, 1910, p. 126.

This striking species is one of the most distinctive of Palaeozoic Echini. Test high, spheroidal, perhaps nearly or quite spherical. In the type (Plate 16, fig. 1) at the upper part of the specimen, which I take to be about on the line of the mid-zone, the ambulacrum measures 8 mm. in width; the interambulacrum 52 mm. in width. From these measurements the circumference must have been in the neighborhood of 300 mm. and the diameter about 100 mm., a very large sea-urchin, but no complete specimen is known. In the ambulacrum, every third plate is wider and higher than the intermediate, so that in this character the structure is very different from that of *Archaeocidaris*. In the type specimen at the mid-zone (Plate 17, figs. 1, 3) the ambulacral plates are rather irregular in form; while usually all plates cross the half-area, occasional smaller plates may be excluded from the interambulacrum, or the center of the ambulacrum, thus making them occluded or demi-plates. Ventrally in the type, and at the mid-zone in younger specimens (Plate 17, figs. 1, 8, 12), all the plates cross the half-area and the large plate of the triplet abuts distinctly against the two smaller plates of the opposite half-area. The ambulacral plates imbricate moderately adorally, and bevel under the adradials. The interambulacrum is very wide, and in the type has eight columns of plates at the mid-zone, but in two smaller specimens (Plate 17, figs. 9, 11) there are only six columns of plates in an area. The interambulacral plates imbricate moderately dorsally and laterally. The character of the tubercles is as described for the genus. The primary spines are cylindrical, with scarcely any perceptible tapering; the largest seen, yet not quite complete, measures 35 mm. in length. The spines are longitudinally finely striate. Small secondary spines occur associated with the secondary tubercles (Plate 17, fig. 10). The pyramids are wide-angled, foramen magnum moderately deep, lateral wings with ridges for the attachment of interpyramidal muscles, all practically the same as in *Archaeocidaris*.

This species is known only from the Lower Burlington Limestone, Lower Carboniferous, Burlington, Iowa. The holotype is in the Museum of Comparative Zoölogy Collection 3,026; also a number of other specimens are in the same collection. A fine series of twelve specimens is in Mr. Frank Springer's collection.

In the type and in part in other specimens, the introduction of the interambulacral columns is shown. As seen in Plate 17, fig. 9, there are four columns of plates in an interambulacral area ventrally, and apparently four in the basicoronal row, as in *Archaeocidaris*. Passing dorsally, new columns are introduced with a pentagonal plate, and a heptagonal plate lies ventral to the same. On the basis of introduction of columns and also on the direction of imbrication, I have oriented the type as shown in Plate 16, fig. 1, and Plate 17, fig. 1. This is reversed from the position given by Meek and Worthen.

Family LEPIDOCENTRIDAE Lovén.

Lepidocentridae (pars) Lovén, 1874, p. 39; (pars) Zittel, 1879, p. 482; (pars) Jackson, 1896, p. 241.
Archaeocidaridae (pars) Lovén, 1874, p. 39; (pars) Duncan, 1889a, p. 8; (pars) Jackson, 1896, p. 241.
Rhoechinidae (pars) Lambert and Thiéry, 1910, p. 121.

Test spheroidal or flattened horizontally, in the plane of the ambitus circular, pentagonal, or elongate through the axis III, 5. Two columns of plates in an ambulacral area, all primaries, or, in one species, occasional alternate plates slightly occluded. Pore-pairs uniserial, or in one species slightly biserial. Ambulacral plates imbricating adorally and beveled strongly under the adradials. Interambulacra with numerous, 5 to 14, columns of plates in an area, moderately thin to very thin. Primordial interambulacral plates are in the basicoronal row; the interambulacra usually have a very accelerated development, additional columns coming in early and rapidly. Interambulacral plates imbricate strongly aborally and from the center outward and over ambulacrals. The peristome is plated with many rows of ambulacral plates only. Oculars are small, insert; genitals wide, low, with many pores as far as known. Periproct with many small angular plates. Apical disc small. Lantern inclined, composed of forty pieces. There are five genera, including two new ones.

KONINCKOCIDARIS Dollo and Buisseret.

Koninckocidaris Dollo and Buisseret, 1888, p. 959; Duncan, 1889a, p. 9.
Perischodomus (pars) Tornquist, 1897, p. 725.
Lepidechinus (pars) Lambert and Thiéry, 1910, p. 122.

Test spheroidal, ambulacra narrow, with two columns of plates in an area. The plates are rather high, and imbricate adorally and strongly bevel under the adambulacrals; pore-pairs are uniserial. Interambulacra wide, with many (seven to eight) columns of plates in an area; the plates are nearly rhombic in outline, imbricating strongly aborally and from the center laterally and over the ambulacrals. Base of corona, peristome, and lantern unknown. Oculars small, genitals low, plates of periproct as far as known numerous, angular. This genus differs from *Lepidocentrus* in that the ambulacral plates are relatively high instead of low. Since for ambulacral plates to be high is a primitive character, it is considered a lower genus than *Lepidocentrus* and one of the two species, *K. silurica*, is geologically much older than any known *Lepidocentrus*.

Type species *K. cotteawi* Dollo and Buisseret from the Lower Carboniferous of Belgium.

Key to the Species of *Koninckocidaris*.

Ambulacral plates high, two equaling the height of an adambulacral; seven columns of plates in an interambulacral area *K. cotteawi* Dollo and Buisseret, p. 285.

Ambulacral plates high, three equaling the height of an adambulacral; eight columns of plates in an interambulacral area. *K. silurica* sp. nov., p. 285.

Koninckocidaris cotteau Dollo and Buisseret.

Koninckocidaris cotteau Dollo and Buisseret, 1888, p. 959.

Perischodomus [cotteau] Tornquist, 1897, p. 725.

Lepidechinus cotteau Lambert and Thiéry, 1910, p. 122.

Known from a fragment of a test and isolated plates. General form unknown, but probably it was spheroidal as is *K. silurica*. Apical disc and jaws unknown. Ambulacral plates high, two about equaling the height of an adambulacral plate; pore-pairs lie near the next adjacent interambulacrum, two pores to each plate, not on a line, but one higher than the other. Dollo and Buisseret say that the pore nearer the middle of the area is higher up. This is opposed to what I have found in all Palaeozoic species, and probably they had their fragment incorrectly oriented. If we change the orientation, then it would read, pore nearer the middle of the area lower, which is in accord with what I find in Palaeozoic and most modern Echini (p. 57). Ambulacral plates bear numerous secondary tubercles, similar to those on the interambulacra. Interambulacra with seven columns of plates, the central column narrower, plates polygonal, strongly imbricating, and ornamented with secondary tubercles; the adambulacral plates bear in addition marginally a primary perforate tubercle. Described from a single specimen, which has not been figured.

Lower Carboniferous, Belgium.

***Koninckocidaris silurica** sp. nov.

Plate 19, fig. 1; Plate 20, figs. 5, 6.

It was with keen delight that I received this most interesting fossil which Professor H. L. Fairchild most kindly sent me for study. It occurs in the Niagara Limestone, Silurian, and therefore is much earlier geologically than any American echinoid previously known. It also adds much to our knowledge of this very interesting ancient genus. The specimen is an internal view and the plates are beautifully preserved, but one must bear in mind that as it is internal, therefore the direction of imbrication is opposite to what it would be if the specimen were viewed from the exterior (compare text-figs. 32-38, p. 75).

Test high, spheroidal, as gathered from the dorsal portion, which alone is preserved. The lower part of the specimen is probably at or near the plane of the mid-zone. Height of specimen 52 mm., width of ambulacrum J at the lower portion 9 mm.; width of the interambulacrum on same line about 43 mm. From these figures the circumference would be about 260 mm. and the diameter in the neighborhood of 83 mm. Ambulacra rather wide, much wider than they would be on the exterior, on account of the lateral beveling of ambulacral plates under (but here over) the adradials. Pore-pairs relatively near the ventral part of each plate, and near the middle of the area, largely due to its being an internal view (compare Plate 20, figs. 9, 10). Ambulacral plates are high, about three equaling the height of an adambulacral plate; in this

respect they are somewhat lower than in *K. cotteau* as described, but much higher than in species of *Lepidocentrus*. A general depressed area surrounds the pore-pair, extending on to the next plate in this internal view. This leaves an elevated ridge between succeeding pore-pairs, and the general superficial appearance resembles the ribs of a turtle in relation to the carapace. Ambulacral plates imbricate adorally and bevel strongly under the adambulacrals. (As this is an internal view, the exact opposite appears in the specimen; that is, ambulacral plates in this view imbricate aborally and laterally bevel over the adradials; compare text-fig. 37, p. 75.)

The interambulacrum is composed of eight columns of plates, which are nearly rhombic in outline, much as in *Lepidocentrus mülleri*. A median column is narrower than the others and in both areas this is column 7. The plates imbricate strongly aborally and from the center laterally and over the ambulacrals. (As this is an internal view, the exact opposite appears to be the case; that is, interambulacral plates in this view imbricate adorally and under the ambulacrals; compare text-fig. 34, p. 75.) The ventral part of the test is unknown, but dorsally an ocular which is low but exceptionally wide, covers ambulacrum B and in part interambulacra A and C on either side. A very low genital is in A and a part of one in C. A small plate between genital A and ocular B may be a displaced plate, but it appears as if the periproct met the interambulacrum in this area like the condition common in Recent Echinothuriidae (text-fig. 170, p. 149; p. 287). The apical disc in this species is evidently small in proportion to the diameter of the test, a progressive character. A few small angular plates lying dorsal to the ocular and genitals are apparently remnants of the periproct. As the exterior of the plates is unknown, surface characters cannot be given; but they are probably as in *K. cotteau*.

This choice and beautifully preserved specimen was collected in 1909 by Mr. A. W. Giles from the base of the Rochester Shale, about ten feet above the Irondequot Limestone, in the Niagara Group, Silurian. It was found in these beds in a ravine of the Genesee River in the north part of Rochester, New York. On the slab are fragments of other fossils including a faceted eye of *Dalmanites limulurus* Green, a typical Niagara Group trilobite. The holotype with two additional fragmentary pieces is in the collections of the University of Rochester, at Rochester, New York, and was loaned to me by my friend, Professor H. L. Fairchild of that institution.

LEPIDOCENTRUS Müller.

Lepidocentrus Müller, 1857, p. 258; Schultze, 1866, p. 123; Lovén, 1874, p. 39; A. Agassiz, 1881, pp. 79, 80; Duncan, 1889a, p. 9; Jackson, 1896, p. 222; Lambert and Thiéry, 1910, p. 121.

Test spheroidal, ambulacral areas narrow throughout, plates low, imbricating adorally and beveled under adambulacrals; pore-pairs uniserial, situated toward the next adjacent interambulacrum, as seen externally, but near the middle of the plate as seen internally. Inter-

ambulacral areas with many (5 to 11) columns of plates which are moderately thin and imbricate strongly aborally and from the center outward and over ambulacrals. Interambulacral plates are rhombic, or more or less hexagonal, and the primordial interambulacral plates are in the basicoronal row. Peristomal plates are unknown in this genus. Mr. Agassiz (1881, p. 79) says that in *Lepidocentrus* there is no distinct line of division separating the coronal interambulacral plates from those belonging to the actinal membrane. He further says that in a remarkably well preserved specimen from the Lower Burlington Limestone, the ambulacral plates are continued to the very teeth, and the same is the case with the interambulacral plates. Unfortunately Mr. Agassiz did not figure this structure, or mention in what species it occurred. The peristome is not known to me in this genus, but in two other genera of the family, only ambulacral plates exist on the peristome, and such a structure as Mr. Agassiz describes is not known to me in any sea-urchin, fossil or Recent. The genus is not known from the Burlington Limestone excepting as implied by Mr. Agassiz's remarks, and this is the first mention of its occurrence in America. It is on this statement apparently that Duncan (1889a) records the genus from this country. Insert oculars, and genitals with many pores are known in one species, the new *L. whitfieldi* (Plate 21, fig. 5). The apical disc is proportionately small.

Mr. Agassiz (1881, p. 80) says of *Lepidocentrus* that, "the genital plates bear about the same proportion to the plates of the anal system which we find in some of the recent Echinothuridae, and there exists at the apical extremity of the coronal plates the same difficulty in defining where the interambulacral plates terminate and the plates of the apical system begin." I do not know the basis of Mr. Agassiz's statement, but in this genus, *Lepidocentrus*, and in all Palaeozoic Echini that I know (excepting possibly *Koninckocidaris silurica*, p. 286) the genital and ocular plates, when preserved, are in contact throughout, so that the interambulacra are separated from the periproct by the oculo-genital ring, not in contact with it, as may occur in the Echinothuriidae (text-fig. 170, p. 149; p. 414).

Lepidocentrus occurs in the Devonian and Lower Carboniferous; the type species is *L. eifelianus* Müller.

*Key to the Species of Lepidocentrus.*¹

Five columns of interambulacral plates in an area *L. rhenanus* (Beyrich), p. 288.

Eight columns of interambulacral plates in an area *L. drydenensis* (Vanuxem), p. 288.

Ten or eleven columns of interambulacral plates in an area, the plates nearly rhombic in form

L. mülleri Schultze, p. 289.

Eleven columns of interambulacral plates in an area, the plates small and rounded hexagonal

L. whitfieldi sp. nov., p. 290.

Number of columns of interambulacral plates in an area unknown, plates similar to those of *mülleri*, but thinner and more rounded in outline *L. eifelianus* Müller, p. 291.

¹ Three species of *Lepidocentrus*, namely *L. desori*, *duponti*, and *gaudryi*, of which no description has been published, are considered under *Nomina Nuda*.

****Lepidocentrus rhenanus* (Beyrich).**

Plate 20, fig. 7.

Palaechinus rhenanus Beyrich, 1857, p. 4; Quenstedt, 1875, p. 377, Plate 75, fig. 18.¹*Lepidocentrus rhenanus* Müller, 1857, p. 264, Plate 4, figs. 4-6; Lovén,² 1874, p. 40; Jackson, 1896, p. 244; (pars) Klem, 1904, p. 17; Lambert and Thiéry, 1910, p. 122.

Test spheroidal, ambulacral plates low. Interambulacrum with five columns of plates which are nearly hexagonal, as seen in area E of Plate 20, fig. 7. The primordial interambulacral plate is in the basicoronal row, and from this it is inferred that the same occurs in other species of the genus. Columns 2, 3, 4 originate in succeeding rows of plates, and column 5 appears in the sixth row. There are powerful jaws in place ventrally. The type and only known specimen, which is in the Berlin Museum für Naturkunde, is an internal mold, and therefore the external character of the plates is unknown. The plates also are probably more hexagonal in outline than they would be on the exterior (compare text-figs. 32-34, p. 75).

Devonian, Wipperfürth, Prussia.

****Lepidocentrus drydenensis* (Vanuxem).**

Plate 16, fig. 5; Plate 21, figs. 1-3.

Echinus drydenensis Vanuxem, 1842, p. 184.*Eocidaris drydenensis* Hall, 1868, p. 298; 1870, p. 341; Lovén, 1874, p. 43; Klem, 1904, p. 71.*Archaeocidaris drydenensis* Keyes, 1895, p. 184; Jackson, 1896, p. 214.

This species has never been figured before, and, as indicated in its synonymy, has been variously placed generically. The type, which may be considered the best preserved individual, is on a large slab with the faint impressions of two or more other individuals. The plates themselves are not preserved, but we have an impression only with the plates entirely dissolved away. This is true of the spines as well as the plates. The best impression is fortunately of the ambulacral areas and of the spines, while the impression of the interambulacral areas is for the most part weak and ill defined. Diameter through J, E, 70 mm., also through H, C. The view, which is ventral, shows a rather deep depression in the oral region. Diameter of the peristome 6 mm. The shape of the test was doubtless spheroidal, or spherical. Ambulacral areas narrow, plates low, about seven or eight equaling the height of an adambulacral plate. Ambulacral pore-pairs lie near the next adjacent interambulacrum and are on an angle, the outer pore a little higher than the inner; width of an ambulacrum at the mid-zone 14 mm.

¹ Non *Palaeocidaris rhenanus* Quenstedt, 1875, p. 377, Plate 75, figs. 30-37 (for which in this memoir see *Xenocidaris clavigera*).

² Lovén writes "*L.[epidocentrus] rhenanus (Palaeocidaris)* Beyrich," thus indicating that Beyrich put the species in *Palaeocidaris*, which is a mistake, as he put it in *Palaechinus*. *Palaeocidaris rhenanus* is Quenstedt's name, applied to another species; here referred to *Xenocidaris clavigera* as a synonym, see under *Incertae Sedis*.

The plates of the interambulacra are marked as impressions, the outlines of which are largely ill defined. There are apparently nine columns of plates in each area, as shown in Plate 21, fig. 1. The spines are marked as depressions or elevations in the shale; they are elongate and slender, acicular, and the clearest impressions are about 8 mm. long.

In the shaly sandstones of the Chemung Group, Upper Devonian, Dryden, Tompkins County, New York; holotype and only known specimens (on a single slab) in the New York State Museum Collection 4,200.

This species is geologically the oldest known sea-urchin from America, except the *Koninckoidaris silurica* herein described. It is not strange that this species has not been figured before, as it is not easy to make out. Professor John M. Clarke kindly sent me the specimen for study, and after careful examination I feel that it should be referred to *Lepidocentrus*. It certainly has no relation to *Archaeocidaris*, and does fit in with the characters of *Lepidocentrus*. As regards the characters of tubercles and spines, primary and secondary, nothing can be definitely said except that the larger spines would compare well enough with the larger spines of *Lepidocentrus*.

****Lepidocentrus mülleri* Schultze.**

Plate 19, figs. 2-5; Plate 20, figs. 8-13.

Lepidocentrus mülleri Schultze, 1866, p. 124, Plate 13, figs. 1-1f; Lovén, 1874, p. 40; Jackson, 1896, p. 223, text-fig. 2; Klem, 1904, p. 17.

Lepidocentrus mulleri Lambert and Thiéry, 1910, p. 122.

Test spheroidal as gathered from the upper part, which alone is preserved. Ambulacra at the lower part of the type specimen about 5 mm. wide; interambulacrum about 65 mm. wide. This would give a circumference of about 350 mm. and diameter of about 111 mm. The ambulacra are narrow, plates imbricating ventrally, and strongly beveled under the adradials. The ambulacra, on account of this bevel, are much wider on the interior of the test than on the exterior, as seen by comparing Plate 20, figs. 9, 10. The pore-pairs on the exterior lie near the adradial plates, but proximally are in about the middle of each ambulacral plate. Interambulacra are broad, with eleven columns, as shown in Plate 20, fig. 8, area A, the only complete area known; but in area C, of the same figure, there are apparently only ten columns. In area A many columns drop out passing dorsally, namely, columns 6, 5, 11, 10, 9, and in the sequence stated. This is a very marked character, indicating reversion or senescence. In my earlier paper (1896, p. 223) this dropping out of columns was by error taken for the coming in of columns, with the result that I oriented the specimen incorrectly, and also incorrectly stated the direction of imbrication (p. 76). The interambulacral plates are thin, nearly rhombic in outline, and imbricate strongly aborally (not orally as I stated before), and from the center outward and over the ambulacra. The beveled edges are shown well in Plate 20, figs. 11, 12.

The interambulacral plates bear one or occasionally two small eccentric perforate primary tubercles with scrobicules, and scattered secondary tubercles. These are shown best in the Munich specimen (Plate 19, figs. 3, 4). The spines are small primaries and secondaries. From the swollen base they taper to the tip and are longitudinally finely striate. This species is known from two good specimens: the type from the Schultze Collection in the Museum of Comparative Zoölogy, and a specimen in the Munich Museum, both figured here. The Munich specimen is especially clear in its surface characters, and the interambulacral plates lie very nearly in horizontal rows instead of alternating in adjacent columns, as usual in Echini. Besides tubercles, it shows a number of spines in place, which are also figured enlarged. Isolated interambulacral plates are fairly common in collections.

Middle Devonian, Gerolstein, Prussia, two fine specimens, the holotype, from the Schultze Collection, Museum of Comparative Zoölogy 3,040; and one in the Munich Museum. Spines from the same locality, including those figured by Schultze, Museum of Comparative Zoölogy Collection 3,043. Isolated plates from same locality, Museum of Comparative Zoölogy 3,042, 3,045; British Museum E 1,201; Strassburg Museum; Freiburg i. B. Museum; Pelm, Prussia, Museum of Comparative Zoölogy Collection 3,103-3,105; Rommersheim, near Prum, Prussia, Museum of Comparative Zoölogy 3,041.

****Lepidocentrus whitfieldi* sp. nov.**

Plate 19, figs. 6, 7; Plate 21, figs. 4, 5.

Lepidechinus rarispinus (pars) Hall, 1868, p. 295 (non Plate 9, fig. 10); 1870 (revised edition), p. 340 (non Plate 9, fig. 10); (pars) Jackson, 1896, p. 228; (pars) Klem, 1904, p. 22.

Test spheroidal, flattened on the base, probably from pressure. Known only from an internal mold. Ambulacral areas narrow throughout, plates low. Eleven columns of small plates in an interambulacral area, the plates strongly rounded in outline. The primordial interambulacral plate is in the basicoronal row, as shown in one area. The oculars, as indicated by an impression, are small, insert; genitals high, with numerous genital pores, nine or ten in the impressions preserved. Professor Hall included this specimen in his *Lepidechinus rarispinus*, here called *Hyattechinus rarispinus*. It differs from that species in that the ambulacra are narrow throughout, instead of broad and petaloid ventrally, as in *rarispinus*. This difference Professor Hall was not aware of, as he had only the dorsal part of *rarispinus* (p. 395). I think it also differs in its spheroidal form, as *rarispinus* is almost certainly highly flattened, (p. 292) but this might well be only a specific, not a generic difference. This species I name in memory of the late Professor R. P. Whitfield of the American Museum of Natural History.

Waverly Group, Lower Carboniferous, Licking County, Ohio. Holotype, and only known specimen, American Museum of Natural History Collection 6,391.

****Lepidocentrus eifelianus* Müller.**

Plate 20, fig. 14.

Lepidocentrus eifelianus Müller, 1857, p. 258, Plate 3, figs. 1-8; Schultze, 1866, p. 123, Plate 13, figs. 2-2c; Lovén, 1874, p. 40; Quenstedt, 1875, p. 374, Plate 75, figs. 14-17; Jackson, 1896, p. 225; Klem, 1904, p. 16; Lambert and Thiéry, 1910, p. 122.

This species, the type of the genus, is known only from isolated interambulacral plates and spines. The plates are thinner and more rounded in form than those of *L. mülleri*, but with similar surface ornaments. The spines are similar to those of *mülleri*.

Devonian, Nohn, and Rommersheim, from the Schultze Collection, Museum of Comparative Zoölogy 3,061, 3,068, 3,069; Berlin Museum für Naturkunde, doubtless the types.

TORNQUISTELLUS Berg.

Leptechinus Tornquist, 1897, p. 785 (non Gauthier, Echinides fossiles de la Tunisie, 1869).

Tornquistellus Berg, 1899, p. 77.

Known only from interambulacral plates, which are small, thin, imbricating, with sparsely distributed secondary tubercles. While the material is so meager, its affinities are distinctly with *Lepidocentrus*, from which it differs in having secondary tubercles only.

Type species *T. gracilis*.

****Tornquistellus gracilis* (Tornquist).**

Plate 20, fig. 15.

Leptechinus gracilis Tornquist, 1897, p. 785, Plate 20, fig. 5.

Tornquistellus [*gracilis*] Berg, 1899, p. 77.

Perischodomus gracilis Lambert and Thiéry, 1910, p. 122.

Known only from isolated interambulacral plates, which are thin, flat, wider than high, slightly angular, but very nearly rhombic in outline. The type specimen measures 8 mm. in width and 5 to 6 mm. in height. The surface is ornamented with about 20 small tubercles. This species has characters which would not fit into any other genus, so that, although so little is known of it, Tornquist was quite justified in establishing a new genus for its reception.

Lower Carboniferous, rare at Hunsrück, Germany; holotype, in the Strassburg Museum Collection.

HYATTECHINUS gen. nov.

Test spheroidal or flattened; through the ambitus nearly circular; pentagonal or elongate through an axis passing through an ambulacrum and opposite interambulacrum, which I take to be the axis III, 5. Ambulacra wide, petaloid ventrally, narrow dorsally. Two columns of plates in each ambulacral area, plates relatively high and wide ventrally, lower and narrower

dorsally; pore-pairs uniserial. Interambulacra with in each area numerous (11 to 14) columns of thin, small plates, imbricating aborally and from the center laterally. Primordial interambulacral plates are in the basicoronal row; above this zone additional columns come in rapidly in succeeding rows, showing a very accelerated development. The peristome is small, with ten columns of ambulacral plates only. Oculars small, insert, covering the ambulacra, and in part the interambulacra on either side. Genitals are large and high. The apical disc is small. Periproct, as far as known, with many small, angular plates. The lantern is strongly developed and inclined, as in other Palaeozoic species.

The type species is *H. beecheri* sp. nov. from the Waverly Group of Warren, Pennsylvania. This genus contains one of the most distinctive groups of known fossil Echini, remarkable alike for the specialized ambulacra and interambulacra. The latter attain the largest number of columns of plates known in the class, with a very accelerated development, yet all the plates are retained, since there is no ventral resorption of the corona, and ventrally one can read stages in development marked by the coming in of columns; dorsally stages in senescence, as marked by the dropping out of columns, without a single break. The flattened form of *rarispinus*, the strongly pentagonal form of *pentagonus* and the bilaterally symmetrical form of *beecheri* mark these as specialized and highly unusual sea-urchins (p. 225).

I take keen pleasure in naming this genus for the late Professor Alpheus Hyatt, one of the finest minds and finest natures that has graced science in this country, to whom I owe all that a pupil can owe to a master.

Key to the Species of Hyattechinus.

Test flattened, nearly circular, eleven to thirteen columns of plates in each interambulacral area

H. rarispinus (Hall), p. 292.

Test pentagonal, fourteen columns of plates in each interambulacral area *H. pentagonus* sp. nov., p. 295.

Test clypeastriform, flattened on the base, bilaterally symmetrical through an ambulacrum and opposite interambulacrum, eleven columns of plates in each interambulacral area . . . *H. beecheri* sp. nov. p. 297.

***Hyattechinus rarispinus** (Hall).

Plate 21, fig. 6; Plate 22, figs. 1-8; Plate 23, figs. 1-7.

Lepidechinus rarispinus (pars) Hall, 1868, p. 295, Plate 9, fig. 10; 1870 (revised edition), p. 340, Plate 9, fig. 10; (pars) Keyes, 1895, p. 192; (pars) Jackson, 1896, p. 226, Plate 7, fig. 42; (pars) Klem, 1904, p. 21; Lambert and Thiéry, 1910, p. 122. (Sec p. 290 and footnote, p. 394.)

Lepidocentrus rarispinus Meek, 1874, p. 375.

This interesting species is known from abundant material. The specimens are all internal or external sandstone molds, very flat, without distortion or separation of plates, which indicates that in life the test was much flattened, probably about as in the Recent *Phormosoma*, or *Echinarachnius*. Plates are extremely thin; they are for the most part wanting, but some

fragments of plates in Yale Museum specimens are only a small fraction of a millimeter in thickness. The test was nearly circular in outline but slightly elongated through an ambulacrum and opposite interambulacrum, as in Plate 22, figs. 1, 8, indicating a tendency to the bilateral symmetry which is more marked in *H. beecheri* (Plate 24, figs. 5-8). The ambulacrum is broad, petaloid ventrally, at its widest part twice the width of the same area at the mid-zone. Ambulacral plates are relatively high, especially ventrally, where one and one-half about equal the height of an adradial plate; dorsally about two and one-half equal the height of an adradial. This shows that the younger ventral plates are higher, which I believe is a more primitive character than that seen in the lower, later built dorsal plates. Pore-pairs are uniserial, in well marked peripodia, and each pair ventrally is on an angle, with the outer pore distinctly higher than the inner. Ambulacral plates bear small secondary tubercles only, and ventrally on the interior (Plate 23, figs. 2, 7) each plate bears a spinose projection that extends into the interior of the test. This spinose projection lies between the inner pore and the middle of the area; it is otherwise known amongst fossils in *H. beecheri* only, as here described, and amongst Recent Echini can be directly compared with the internal spines that I show in *Phyllacanthus* and *Eucidaris* (Plate 3, figs. 12, 13; p. 61).

The interambulacra have from 11 to 13 columns of plates at the mid-zone, this range being shown in a single specimen in its several areas (Plate 23, fig. 3). The type specimen, however, (Plate 21, fig. 6), has 11 columns in each of the three areas preserved. The primordial interambulacral plates are in place in the basicoronal row (Plate 23, fig. 1), and new columns come in rapidly, one, or sometimes two columns appearing in each row as added up to the ninth, but later columns may come in more slowly. Dorsally, the adambulacral or even additional columns drop out on approaching the apical disc, indicating senescence. The interambulacral plates bear a small eccentric primary tubercle with secondary tubercles (Plate 23, figs. 5, 6), to which are attached corresponding small spines. The peristome is covered with ten columns of ambulacral plates only (Plate 23, fig. 1), much as they are in a Recent echinothuriid (text-fig. 43, p. 80). I (1896) first showed these rather imperfectly in *rarispinus*, and Mortensen thought it made a connection between the two genera, but I cannot agree with this view, as elsewhere discussed (p. 213). The ocular, genital, and periproctal plates are unknown in this species, but they were probably similar to those of *pentagonus*. A powerful lantern is represented by molds of the parts (Plate 23, fig. 2) in several specimens. The pyramids are wide-angled, and therefore the lantern is inclined, as in other Palaeozoic types.

Waverly Group, Lower Carboniferous, Meadville, Pennsylvania; the holotype (Plate 21, fig. 6; Plate 22, fig. 7) is from this locality, and is in the American Museum of Natural History, no. 6,392. Same horizon, Warren, Pennsylvania; a superb series of ten specimens largely collected by the late Professor C. E. Beecher, is in the Yale University Museum nos. 324-333; another fine series of six specimens from the same locality is in the New York State Museum no. 1,799.

On account of the exceptional quality and interest of the material, some detailed discussion of the specimens is desirable. The type (Plate 22, fig. 7; Plate 21, fig. 6) is a fine sandstone mold of the dorsal portion of the test (p. 395). It has three ambulacra and interambulacra preserved, and its periphery coincides with the mid-zone. This was the only specimen of this species known to Hall, as his second specimen is considered here as belonging to a distinct species and genus, namely *Lepidocentrus whitfieldi*, p. 290. In this type specimen the ambulacra are narrow and the plates are relatively narrow and low, as it is a dorsal view. In each interambulacrum there are eleven columns of plates, the eleventh originating above the mid-zone as shown. In each interambulacral area the adambulacral columns drop out in passing dorsally, as a senescent character. As it is an external mold, the lettering is reversed from what it would be if seen from the interior (p. 21).

The Yale Museum specimen shown in Plate 22, fig. 8, Plate 23, fig. 3, is also a sandstone impression of the dorsal side, but from Warren, Pennsylvania. Being an external mold, therefore the lettering is reversed, and it is the most nearly complete dorsal area known. The ambulacra are narrow and plates relatively narrow and low. Interambulacra A and G have eleven columns of plates each. In area I there are twelve, and in C and E, thirteen columns of plates, thus showing considerable radial variation. In each area the adambulacral columns 1, 2 drop out dorsally, when columns 3, 4 assume an adradial position near the apical disc. Five radial depressed pits appear, seen best in Plate 22, fig. 8, which are evidently due to a forcing up of the test at these points when, in flattening, the lantern came in contact with the dorsal area.

A remarkable specimen in the Yale Museum from Warren, Pennsylvania (Plate 22, figs. 1, 2; Plate 23, figs. 1, 2, 7) is one of the most interesting Echini that I have studied. As seen, the specimen consists of counterparts which structurally supplement each other. In one of these (Plate 22, fig. 1; Plate 23, fig. 1) we have for the most part an external sandstone mold of the ventral side, showing beautifully the impressions of ambulacral, interambulacral, and peristomal plates, with sutures, tubercles, and peripodia. With this there is in areas B, C, and imperfectly in D, an internal impression of the dorsal side, molded on the sand which filled the interior of the test. In the reverse counterpart (Plate 22, fig. 2; Plate 23, figs. 2, 7) we have in part in areas J, A, B, and C an external mold of the dorsal side showing tubercles, etc., but for the most part the specimen shows an internal impression of the ventral side molded upon the sand which filled the interior of the test. On this part there are no tubercles or peripodia, as it represents the proximal faces of the plates, but there are impressions of suture lines, pore-pairs, the spinose projections from the interior of ambulacral plates, and the lantern. Such a condition was rendered possible only by a complete solution of the calcareous parts leaving on one side an external and on the other an internal impression of these parts. Considering the structure, it is seen (Plate 23, fig. 1) that the ambulacral plates of the peristome pass directly into those of the corona, and the plates of the corona are as given in the description of the species.

In area B the ambulacral plates of the dorsal side are brought into almost immediate contact with those of the ventral side, superposing a narrower upon a wider plate. It is a similar contact which I think accounts for the so called roofing plates of Sollas (1899, p. 705) in *Palaeodiscus*, as elsewhere discussed (p. 251). In the internal view (Plate 23, figs. 2, 7) a series of slanting pits exists between the inner pore and middle of the ambulacrum and represents molds of the spinose processes, which extend into the test as described. The interambulacral areas all show the primordial plate in place as I earlier described it (1896, p. 226). This plate is directly comparable to the similar plate seen ventrally in *Bothriocidaris*, in the young of all other Echini, and in the adults of types where it has not been removed by resorption in the advance of the peristome. In the second row there are two plates in each area, and in the third row three plates in each interambulacral area (Plate 23, fig. 1). In the fourth row there are four plates, but in area E the fifth column is also represented by a plate in the fourth row, a case of extreme acceleration of development. Columns 6, 7, 8, 9 come in rapidly, a new one being added in each succeeding row as built. The mold of the lantern (Plate 23, fig. 2) shows casts of the five interradial alveolar cavities, each of which was surrounded by two half-pyramids, and also casts of the radial spaces between the half-pyramids seen best in areas B and D, which were originally occupied by the interpyramidal muscles. Evidently the lantern was inclined with the usual structure of the Palaeozoic lantern, as in Plate 27, figs. 4-6 (p. 22).

Another specimen from the Yale Museum (Plate 22, figs. 3-6) shows certain differences from that just described. The figures 3 and 5 are external molds of the ventral side, with tubercles, spines, and peripodia. The figures 4 and 6 are external molds of the dorsal side of the same individual specimens, and also show the surface characters of tubercles, etc. A mold of the interior of the plates is shown in a small portion only of area J. In two areas of figure 4 and in a third area of the counterpart, figure 3, there are eleven columns of plates, as in the type specimen. The impression of ambulacral plates on the peristome is very clear in figure 3, and the mechanical displacement caused by the thrust of the lantern during flattening is clear in figure 4.

This material was collected by my friend, the late Professor Beecher, near his old home at Warren, Pennsylvania. It is a pleasure to feel that his rare skill as a collector and preparator is still contributing to the science and the principles that he loved so well.

****Hyattechinus pentagonus* sp. nov.**

Plate 19, fig. 8; Plate 24, figs. 1-4; Plate 25, figs. 1-4.

The material of this species is a slab with several exquisitely preserved specimens which Professor R. S. Breed kindly loaned me, and two additional specimens that I received through the same gentleman.

The test is relatively high, though far from spheroidal, and strongly pentagonal in horizontal outline, the apices of the pentagon coinciding with the ambulacral areas. It is the most markedly pentagonal of any known regular sea-urchin. The diameter in different specimens varies from 45 to 60 mm. The ambulacrum is petaloid ventrally, narrow dorsally, 6 mm. wide at the widest part of the petal, which is twice that of the same area at the mid-zone. Ambulacral plates are wide ventrally, narrower dorsally, and ventrally somewhat higher than they are dorsally. Pore-pairs are uniserial, in peripodia, with ventrally the outer pore set somewhat higher than the inner pore of each pair. Interambulacra are very wide, with fourteen columns of plates in each area, the highest number yet known in Echini. The ventral surface is known in only one specimen (Plate 24, fig. 4; Plate 25, fig. 1), but this is very well preserved. It shows that the primordial interambulacral plate is in place in the basicoronal row in each area, two plates in the second row, and three in the third. In area A the fourth column appears in the fourth row, but in areas C, G, and I both columns 4 and 5 appear in the fourth row; and in area E, apparently (partially restored) columns 4, 5, and 6 appear in the fourth row. This is a degree of acceleration of development much ahead of that known in any other type, and may be correlated with the fact that the species attains more columns than are known in any other type. Columns 6 to 11 come in with great rapidity, as shown in the figure, one or more being added in succeeding rows as built. Turning to the dorsal view (Plate 24, figs. 1-3; Plate 25, figs. 3, 4), we see that the columns 13 and 14 come in later and with considerable intervals in the point of introduction, for, as usual in Hyatt's law of acceleration of development, its effect is most marked on the earlier added parts, the later differentiated structures not yet having come within its control. Dorsally, in this remarkable type, we find the dropping out of columns marking reversionary or senescent characters; this is shown in Plate 25, figs. 3, 4. The adambulacral columns 1 and 2 drop out, so that 3 and 4 become in further growth adjacent to the ambulacra; also some additional columns drop out, as 10 and 13 in figure 4. The exterior of the plates is marked by numerous closely set tubercles; but I did not distinguish any division into primary and secondary; rather all seem to be of the second class. The peristome is small, and as in *H. rarispinus*, is plated with ten columns of ambulacral plates only, which appears to be a character of the whole family. Small insert oculars cover the ambulacral areas and laterally in part the interambulacra on either side. Genitals are relatively large and high; no genital pores were recognizable in the sandstone impression. Impressions of a few small angular plates in the periproct show that it is of the usual Palaeozoic character. The lantern and internal characters of the plates are not preserved in known specimens of this species.

Waverly Group, Lower Carboniferous, Meadville, Pennsylvania, slab with the holotype in Alleghany College Collection; paratypes in Museum of Comparative Zoölogy Collection nos. 3,107 and 3,108.

***Hyattechinus beecheri** sp. nov.

Plate 24, figs. 5-8; Plate 25, fig. 5; Plate 26.

This very remarkable sea-urchin is known from a single specimen, which is an internal sandstone mold, and bears the impress of the proximal faces of the plates only. The test is depressed, dome-shaped, flattened on the ventral aspect, elongate and bilaterally symmetrical through an ambulacrum and opposite interambulacrum, which I take to be the axis III, 5. The specimen is so perfect in form, without distortion or separation of plates, that it may be taken as representing the original shape. Excepting as shown somewhat in *Hyattechinus rarispinus*, this is the only regular echinoid known with a central periproct, that presents a bilateral symmetry. The oblong form of the Echinometridae through an oblique axis does not represent a true bilateral symmetry. The specimen measures 26 mm. in height, 80 mm. in length through the axis III, 5, and 71 mm. in width through the peristome and at right angles to the longitudinal axis. While the mold represents only the impression of the interior of the test, it is sufficiently perfect so that I am able to represent the specimen in Plate 26 spread out on the Lovén method in which each plate was scrutinized with utmost care. At a few points in areas 3 and 4 details could not be made out, and in these areas in part the plates are restored as indicated by dotted lines. The breaks occurring in the figure at the ambitus are due to the mechanical requirements of getting over the edge in a specimen of this shape. Only one ambulacrum is filled in in detail dorsally, and for this the best area was selected.

The ambulacra are broad and petaloid ventrally, being 13 mm. in width at the widest part, 9 mm. wide at the ambitus, and 6 mm. wide at about the middle of the dorsal side of the test. The plates are relatively wide and high ventrally, narrow and much lower dorsally. The pore-pairs are uniserial, situated at about the middle of each plate. This is a general character of the interior, and on the exterior they would doubtless have been much nearer to the interambulacra on either side (compare Plate 20, figs. 9, 10). The outer pore of each pair ventrally is higher than the inner pore, as in other species of the genus. Between the inner pore and center of the area a slanting gash-like pit exists in each plate ventrally; these pits, being molds, represent elevated nodose spine-like processes which extended inward from the ambulacral plates (Plate 24, fig. 6), similar to those described in *H. rarispinus* (p. 293), and again, similar to, though less elongate than the spinose processes from the ambulacral plates of *Eucidaris* and *Phyllacanthus* (Plate 3, figs. 12, 13). Such spinose processes from ambulacral plates of the corona are known only in the types mentioned, but Sir Wyville Thomson and Mr. Agassiz described similar internal spines as given off from ambulacral plates of the peristome in *Porooidaris* (p. 61).

The interambulacra are very broad, and make up the greater part of the test, as in all

species of the family. There are eleven columns of plates at the mid-zone in each area; a similar number is seen in some areas of specimens of *H. rarispinus*, but a greater number exists in *H. pentagonus*. The primordial interambulacral plates are in place in the basicoronal row in each area, as in other species of the genus. In the second row there are two plates, in the third row three, and in the fourth row four, these being the point of origin of their several columns. The fifth column originates in the fifth row in areas 1, 5, and 4, but in the sixth row in areas 2 and 3. Likewise the sixth column originates in the sixth row in areas 1, 5, and 4, but in the eighth row in areas 2 and 3. It is to be noticed that a bilateral symmetry is expressed by the rate of coming in of columns five and six; in both they originate a little earlier in the three posterior interambulacra than they do in the anterior two. Too much weight should not be attached to a single observation, but it is in direct accord with what I have found in the symmetrical bilateral development of other structures in various regular Echini. Columns 7 to 11 come in very soon after the sixth, either in succeeding rows, or very nearly so, and the eleventh column is attained at or just above the ambitus in each area. Area 4 is imperfect and column 10 apparently originates far to the left of the center, as indicated in the restoration. Senescence is strongly marked by the dropping out of columns of interambulacral plates in this specimen; the adambulacrals 1 and 2 in all areas excepting 4 drop out early, so that above that point columns 3 and 4 assume an adradial position. In addition, in area 2, columns 7, 11, 10, and 9 drop out passing dorsally, so that near the apical disc there are only five columns remaining, a structure which is a senescent reversion to a similar character seen as a stage in development in its own youth, and doubtless to the adult condition of some adult ancestral stock from which it was evolved. A similar dropping out of interambulacral columns more or less completely occurs also in the other areas. I would not point to it other than as a representative of the family, but it is noteworthy that *Lepidocentrus rhenanus* of the Devonian (Plate 20, fig. 7) has a slow, not an accelerated development, and has five columns of interambulacral plates in the adult.

The peristome is small as in all of the family, and is evidently plated with ambulacral plates only (as in *rarispinus*), although in this specimen they are only partially preserved (p. 287).

The apical disc is imperfectly known (Plate 25, fig. 5), but something can be gathered from the mold. The genitals are fairly clear and are high and wide. Spaces for the oculars exist, although the impress of these plates is not marked. They are restored to fill spaces between the genitals, thus making them all insert. The outline is preserved of a few small angular peri-proctal plates, and others are restored in the figure by dotted lines. A partial mold of the lantern orally shows that this structure existed, and was probably as in other species of the family (Plate 27, figs. 4-6).

I take pleasure in naming this species in memory of my close friend the late Professor Charles Emerson Beecher, of Yale University, thus linking his name with Hyatt's in a species that is one of the most striking of known Echini.

This species, which I make the type of the genus, is represented only by the specimen described, which was collected by the late Dr. F. A. Randall in the Waverly Group, Lower Carboniferous, of Warren, Pennsylvania. Then it came into the hands of the late Professor Beecher, and by him was transferred to the Yale University Museum Collection.

PHOLIDECHINUS gen. nov.

Test high, spheroidal; ambulacra narrow throughout, with two columns of plates in each area. Plates low primaries, all alike, or at the mid-zone alternate plates slightly narrowed at the interambulacral contact; and nearly or quite cut off from that area by the marginal enlargement of their fellows. Pore-pairs are uniserial, or at the mid-zone slightly biserial. Ambulacral plates are thin, imbricate adorally, and bevel strongly under the adradials. Interambulacra wide with many (nine to ten in the species known) columns of plates in an area; the plates are polygonal with very rounded outlines and imbricate strongly dorsally and laterally and over the ambulacrals. Both ambulacral and interambulacral plates bear only secondary tubercles and spines. The primordial interambulacral plates are in the basicoronal row, and succeeding columns come in with a slow, not an accelerated development. Peristome with ambulacral plates only, oculars unknown, genitals low, each with many pores. Lantern low, inclined.

The type and only known species is *P. brauni* of the Lower Carboniferous.

This genus differs from *Lepidocentrus* in that interambulacral plates bear secondary spines only instead of primary and secondary; also in that ambulacral plates at the mid-zone are not all alike and pore-pairs are not strictly uniserial as they are in *Lepidocentrus*. From *Hyatt-echinus* it differs in that the ambulacra are narrow throughout, instead of broad and petaloid ventrally, and the interambulacra have fewer columns of plates, without marked acceleration of development.

**Pholidechinus brauni* sp. nov.

Text-fig. 207, p. 184; Plate 27, figs. 1-6; Plate 28, figs. 1-10; Plate 32, fig. 6.

Of this striking type there is a considerable amount of excellent material. The test is high, spheroidal. In the holotype (Plate 27, fig. 1) the ambulacra measure 5 mm. in width at the mid-zone, and the interambulacra 19 mm. in width. From these measurements the circumference would be about 120 mm. and diameter about 38 mm. The two other specimens figured are somewhat larger. The ambulacra are narrow throughout, with two columns of plates, which are low, imbricating adorally, and laterally strongly beveled under the adambulacrals. The pore-pairs have well marked peripodia. Ventrally the ambulacral plates are primaries, all alike, with pore-pairs uniserial. Above this area and at the mid-zone alternate plates differ somewhat, one plate being a pure primary, but enlarged on its outer margin; the

next coincidentally being narrowed on its outer margin and nearly or quite cut off from contact with the interambulacrum (Plate 28, figs. 5, 6). When quite cut off it becomes thereby occluded. Concurrently with this alternating difference the pore-pairs at the mid-zone are slightly biserial instead of purely uniserial as seen ventrally. The condition is quite comparable to that shown in *Maccoya burlingtonensis* (Plate 33, figs. 1, 2), and is interesting as a parallel taking on of a similar character in an independent family of Echini.

The interambulacra in each area have nine or ten columns of plates which imbricate strongly aborally and from the center outward and over the ambulacra. Each plate, instead of being angular, is so rounded in outline that each bounding edge represents very nearly the segment of a circle; the longest segment lies on the left of the plate in the left half-area and on the right of the plate in the right half-area (Plate 28, fig. 1). This longest segment is formed by the free edge of the plate itself. Three shorter segments of circles of the same arc occur on each plate, formed by the overlapping of neighboring plates on the inner side. The structure is much like that shown in text-fig. 32, p. 75. The middle column that imbricates laterally in two directions presents a long sweeping curve which surrounds the plate excepting for a second short curve on the adoral border where in contact with the next succeeding ventral plate of its series. The nearest thing to which the form of these plates can be compared, perhaps, is the scale of an ordinary teleost fish. In addition, a peculiar feature known in no other sea-urchin, is a very thin, delicate flange which bounds and is limited to the longest segment of the circle on each plate (Plate 28, fig. 9). This flange therefore exists on the long curves on the left side of the left half-area, and on the long curves on the right-hand side of the right half-area. In the median column the flange borders the long curve, which nearly surrounds the plates of this column. The flange is so thin and delicate that it is usually lost by erosion, but it is found in exceptional cases, or in others the slight depression for its reception may be found, not in the plate to which the flange belongs, but in the next contiguous plates. Separated interambulacral plates present a strong bevel toward the center and adorally as seen from above. As surface features, ambulacral and interambulacral plates alike have many secondary tubercles which support small acicular spines. There are no tubercles on the flanges described.

The peristome has ten columns of low, wide plates which alone cover the area. Ocular plates are not known, but low, wide genitals exist (Plate 28, fig. 10), each of two preserved having eight genital pores. A typical Palaeozoic lantern exists as described below.

This species is named for Mr. Frederick Braun of Brooklyn, New York, an ardent and skilful collector, who helped me greatly with the loan of his choicest material.

Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana, Museum of Comparative Zoölogy Collection (five specimens, 3,109-3,114, including the holotype no. 3,109); F. Braun Collection; American Museum of Natural History; British Museum of Natural History Collection E 10,678 (a specimen given by me, the original of Plate 27, fig. 3; Plate 28, figs. 4-6); Yale University Museum Collection 321 and 322 (two very complete lanterns).

In the holotype (Plate 27, fig. 1; Plate 28, figs. 2, 3, 9) there are nine columns of interambulacral plates in each area at the mid-zone, but a tenth appears dorsally in area C. The beveling of plates is seen below the initial plate of column 8, some spines are in place, and the delicate flanges described as bordering the plates are well preserved.

In Mr. Braun's specimen (Plate 27, fig. 2; Plate 28, fig. 1) there are nine columns of plates at the mid-zone in each interambulacral area. The primordial interambulacral plates are in place in the basicoronal row, two plates in the second, three in the third, and four in the fourth row, above which additional columns come in with a moderate, not an accelerated rate of development. Low, wide ambulacral plates cover the peristomal area, and the teeth are in place. The British Museum specimen (Plate 27, fig. 3; Plate 28, figs. 4-6) has ten columns of plates in each interambulacral area, in both originating at or below the mid-zone; ambulacral detail at the mid-zone is clear.

In Yale University Museum there are two lanterns in the D. A. Barrett Collection from Crawfordsville belonging to this species, which are remarkably perfect in preservation, being the best specimens of this structure so far known in any Palaeozoic echinoid. One of these specimens I mentioned in my earlier paper (1896, p. 213), but they have not been described. The two are essentially similar except that one is laterally compressed. The more perfect specimen is shown in Plate 27, figs. 4-6, and in its relations to the lanterns of other representative Echini in text-fig. 207, p. 184. It is important in itself, also because it is typical of all lanterns known from the Palaeozoic formations, others known differing from it only in trifling details. In side view with teeth in place (Plate 27, fig. 6) it is inclined at a very wide angle of about 90 degrees, the width of the top being very nearly twice the total height from the tips of the teeth. This wide angle, which I have described as inclined, is characteristic of all Palaeozoic lanterns, also of the lanterns of young modern regular Echini. The teeth are grooved, meet in a point ventrally, and dorsally extend to a point just above the base of the foramen magnum, so that they are seen in side view. This is evidently the dorsal limit of the calcified portion of the tooth, beyond which the uncalcified portion would doubtless extend in life as in *Strongylocentrotus* (Plate 5, figs. 6, 9). The pyramids are very wide-angled, with a rather shallow foramen magnum. Hollows are on either side of the face view, in which the retractor muscles took origin; the sides of the pyramids are curved, admitting of relatively long interpyramidal muscles. The lateral wings of the pyramid are wide, as in *Oligoporus* (Plate 50, fig. 11), a resultant of the inclined angle of the lantern. A narrow epiphysis caps each half-pyramid, seen in face view (Plate 27, fig. 6), and in dorsal view (Plate 27, fig. 5), it extends inward, narrowing toward the oesophageal cavity. A typical brace rests on and interlocks with the two adjacent epiphyses as shown in ventral, side, and dorsal views. The brace has the usual condyles and other outlines of modern regular Echini. In one area, D, of figure 5, a compass exists, slightly displaced, and apparently fragments of two other compasses in areas B and J. The compass is arched

as usual, but shows no bifid distal end; probably it was worn off, but possibly no bifid tip existed, as in some Recent Echini. In the ventral view (Plate 27, fig. 4) the lantern is in part covered with the ambulacral plates of the peristome, which alone fill this area in the species and the family. It is interesting to see how near the lantern of this ancient type is to the character of the lantern in young modern regular Echini, as discussed (p. 181), the similarities being in the inclined angle, shallow foramen, and wide spaces for long interpyramidal muscles.

Family PALAECHINIDAE M'Coy.

Palaechinidae M'Coy, 1849, p. 253; Lambert and Thiéry, 1910, p. 119.

Palaechinidae (pars) Lovén, 1874, p. 40.

Melonitidae (pars) Zittel, 1879, p. 484; (pars) Duncan, 1889a, p. 15; Jackson, 1896, p. 239.

Archaeocidaridae (pars) Duncan, 1889a, p. 8.

Melonechinidae Lambert, 1899a, p. 53; Lambert and Thiéry, 1910, p. 119.

Melechidae Lambert and Thiéry, 1910, p. 120.

Test high, spheroidal, elliptical, or obovate; ambulacra narrow or wide, with from two to twelve columns of plates in each area at the mid-zone. Two pores to each plate, situated in a peripodium. Pore-pairs uniserial, biserial, or multiserial. Interambulacra wide or rarely narrow, with from three to eleven columns of plates in each area at or dorsal to the mid-zone. Plates moderately to very thick, not imbricating, but ambulacral plates bevel over the adradials on the marginal sutures. The base of the corona is resorbed so that there are two plates in the basicoronal row in each interambulacral area, instead of one plate as in the *Lepidocentridae*. Tubercles and spines are secondaries only, on all plates of the corona, a feature pointed out by M'Coy. Peristome (known only in *Melonechinus*, Plate 56, figs. 7, 8) with many rows of ambulacral and some interradially situated non-ambulacral plates. The apical disc is small, the diameter in the specimens measured being about 13 to 25 % of the diameter of the test, usually it is proportionately smaller than in most Recent regular Echini (pp. 87, 104). Oculars are insert, or rarely one or more to all may be exsert without pores as seen from the exterior. Genitals large, high, with from two to five pores each; a madreporite is rarely recognizable. Periproct with many angular plates. Lantern inclined, rarely preserved, but as far as known, with the typical character of the Palaeozoic. The characters of the ambulacra at the mid-zone are the essential basis for the division of this family into genera and in part into species. The characters of the genera in brief are given in the key (p. 207), and their phylogenetic relations are set forth in the systematic table (p. 209) and in text-fig. 237, p. 231. (See pp. 82, 362, 414.)

The family *Palaeechinidae* was formed by M'Coy (1849) to include *Palaeechinus* and *Melonechinus*, the only genera then known. He defined the group clearly, but his earlier name has largely given place to Zittel's name *Melonitidae*. M'Coy's genus *Palaeechinus* included species that have since been generically divided with some resulting confusion, and some new types are generically different from any species known to M'Coy; therefore it is necessary at this place to give the history of the subject.

Pomel (1869, 1883), the first reviser, included in *Palaeechinus* those species in which ambulacral plates are all primaries and pore-pairs are uniserial, and listed as belonging to this genus *P. quadriserialis* Wright, *P. ellipticus* M'Coy¹, and *P. elegans* M'Coy. Duncan (1889a, p. 3) objected to Pomel's methods and would not accept his genera. I sympathize with his feeling, but cannot see that this is any reason for rejecting Pomel's names. Duncan (1889, p. 205) referred species with this structure (plates all primaries and pore-pairs uniserial) to the genus *Rhoechinus* of Keeping, which was a mistake, as *Rhoechinus* (here, p. 394, considered a synonym of *Lepidechinus* Hall) has imbricate plates, thus differing essentially from *Palaeecchinus*.²

Pomel (1869, 1883) further proposed *Maccoya* as a genus to include species in which ambulacral plates are alternately enlarged and reduced toward the exterior border, from which result two vertical series of pore-pairs in each half-area. Expressed in other words, the genus *Maccoya* is characterized by ambulacral plates, all of which reach the middle of the area, but which are alternately primaries and nearly or quite occluded according as they extend to the interambulacrum or not, and with pore-pairs biserial. Pomel's type of this genus is *Maccoya gigas* (M'Coy), and his observation (1883) was probably based on Baily's (1874, Plate 3, fig. c) figure which is here reproduced as Plate 47, fig. 2. He also and quite correctly included in his *Maccoya* the *Palaechinus burlingtonensis* Meek and Worthen and *P. gracilis* Meek and Worthen. Pomel's (1883) *Eriechinus* with *Palaechinus sphaericus* M'Coy as a type (?)³, and his *Wrightia* (1869) (or *Wrightella*, 1883), with *Palechinus phillipsiae* Forbes as a type I do not recognize as distinct from *Maccoya*, because in both the true *sphaericus* and *phillipsiae* the ambulacral details and other structures as known are essentially the same as in *Maccoya*. In brief, I include in *Maccoya* the species *burlingtonensis* Meek and Worthen, *intermedia* Keeping, *phillipsiae* Forbes, *sphaerica* M'Coy (but not the *sphaericus* of Koninck³), *gigas* M'Coy, and *gracilis* Meek and Worthen (p. 312). Duncan in his (1889) discussion included in his *Palaeechinus* part of the species here referred to *Maccoya* and two species here referred to *Lovenechinus*. In his *Palaeechinus* he included *P. gigas* (p. 304), *P. sphaericus*, *P. ellipticus*¹, *P. intermedius*, *P. phillipsiae*, and suggested, quite correctly, that the two North American species (*P. burlingtonensis* and *P. gracilis*) belong in the same generic group. Duncan's (1889) *Palaeechinus ellipticus* is not the *Palaeechinus ellipticus* of M'Coy as stated.¹

¹ *Palaeechinus ellipticus* M'Coy (p. 307, Plate 29, fig. 2; Plate 30, fig. 10) belongs in this genus, as stated by Pomel but the specimen in the Museum of Practical Geology, figured by Duncan (1889, p. 206, fig. viii) as *ellipticus* is not that species, but is here referred to *Lovenechinus lacazei* (p. 329, Plate 36, fig. 1).

² Professor Duncan included in his *Rhoechinus*, *R. irregularis* Keeping (here referred to *Lepidechinus*, p. 396); *R. elegans* (M'Coy); *R. quadriserialis* (Wright); *R. sp.*, a specimen in the Woodwardian (now called Sedgwick) Museum, Cambridge, England. See footnote p. 394.

³ Pomel's (1883) *Eriechinus* was evidently based not on M'Coy's *sphaericus* but on de Koninck's (1869, 1870) figure of what he called *Palaechinus sphaericus*. Pomel says of his genus that it differs by the structure of the apex, one of the genitals having only a single pore, and this structure is that shown by de Koninck. De Koninck's observations were incorrect, and his specimen was not *Palaechinus sphaericus* M'Coy, but is here referred to *Lovenechinus lacazei* (Julien), where it is fully described (p. 330-334, text-figs. 240-243; Plate 35, fig. 7).

The *Palaeochinus gigas* M'Coy (Plate 46, figs. 1, 2; Plate 47, fig. 2) is referable to Maccoya (p. 321); but Duncan's (1889, p. 206, fig. 1) *Palaeochinus gigas* is doubtless based on the specimen in the Museum of Practical Geology which is here referred to *Lovenechinus anglicus* sp. nov., as shown on p. 346; Plate 46, figs. 5, 6; Plate 47, figs. 3-5.

The new genus *Lovenechinus* has four columns of plates in each ambulacral area at the mid-zone, two columns of demi-, and two of occluded in each half-area, but without isolated plates; the pore-pairs are biserial. This genus includes *Palaeochinus lacazei* Julien, *Oligoporus mutatus* Keyes, *O. nobilis* Meek and Worthen, *O. missouriensis* Jackson, and the two new species *anglicus* and *septies* (p. 326).

The genus *Oligoporus* Meek and Worthen is here used in a restricted sense to include species with four columns of ambulacral plates at the mid-zone, two columns of demi-, and two of occluded plates in each half-area, but with, in addition, scattered isolated plates in the middle of each half-area; pore-pairs are multiserial. This is a structural advance on *Lovenechinus*, and yet not an attainment to the character of *Melonechinus*. This genus includes *Oligoporus blairi* Miller and Gurley, *O. coreyi* Meek and Worthen, *O. sulcatus* Miller and Gurley, *O. halli* sp. nov., and *O. danae* Meek and Worthen (the type), (p. 351).

Norwood and Owen's genus *Melonites*, now called *Melonechinus* Meek and Worthen, includes species of the family in which at the mid-zone there are from six to twelve columns of plates in each ambulacral area consisting of demi-plates, occluded plates, and one to four more or less irregular columns of isolated plates in each half-area. This genus represents the final stage of differential evolution in the family, and the species are based largely on the number of columns of ambulacral plates which they attain. There has never been any question as to what species should be included in this genus, and it is unnecessary to enumerate them (p. 364).

Pomel's (1883) genus *Xystria* was based on *Palaeochinus* (?) *konigii*, and is here considered under *Incertae Sedis* (p. 450).

PALAEECHINUS M'Coy.

Palaeochinus (pars) M'Coy, 1844, p. 171; Pomel, 1883, p. 114; (pars) Lambert and Thiéry, 1910, p. 119.

Palaeochinus (pars) Lovén, 1874, p. 40 (non *Palaeochinus* Duncan, 1889, p. 204; 1889a, p. 13, see above pp. 303, 304).

Rhoechinus (pars) Duncan, 1889, p. 205; 1889a, p. 14 (non *Rhoechinus* Keeping, 1876, for which see *Lepidechinus*, p. 294); (pars) Jackson, 1896, pp. 200, 239; (pars) Tornquist, 1897, p. 754; (pars) Klem, 1904, p. 27; (non *Rhoechinus*, Lambert and Thiéry, 1910, p. 122).

Paleochinus Tornquist, 1897, p. 735.

Test spheroidal or elliptical, ambulacra narrow, with two columns of plates in each area. Ambulacral plates are all primaries alike throughout the area, pore-pairs uniserial. Interambulacral areas wide, with from four to six columns of plates in an area at or above the mid-zone, two plates in the basicoronal row in each area. Peristome unknown; oculars insert,

imperforate, at least externally; genitals wide, high, each with from two to five genital pores; periproct plated with many small angular plates; lantern unknown, but doubtless as in other genera of the family. (See pp. 82, 191.)

Type species, as selected by Lambert and Thiéry (1910, p. 119), *P. ellipticus* M'Coy, of the Lower Carboniferous of Ireland.

This genus includes only part of the species referred to it by M'Coy, and the succeeding history is given under discussion of the family. Duncan (1889a, p. 14) referred the genus (which he called *Rhocchinus*) to his family *Archaeocidaridae* because there are two columns of ambulacral plates, but in this he showed an entire lack of appreciation of other characters, which unquestionably associate the genus with the *Palaecechinidae* not the *Archaeocidaridae*. Structurally this genus is the most primitive member of the *Palaecechinidae* because its ambulatorium is like that found in the young, as a developing stage, in the next three genera of the family; also it is comparable to the young plates seen dorsally as a localized stage in all other genera of the family as set forth diagrammatically in text-figure 237, p. 231.

*Key to the Species of Palaecechinus.*¹

- Four columns of plates in each interambulacral area, test elliptical . . . *P. quadriserialis* Wright, p. 305.
- Five columns of plates in each interambulacral area, test elliptical . . . *P. ellipticus* M'Coy, p. 307.
- Five columns of plates in each interambulacral area, test spheroidal . . . *P. elegans* M'Coy, p. 308.
- Five or usually six columns of plates in each interambulacral area, test nearly or quite spherical . . . *P. (?) minor* sp. nov., p. 310.

****Palaecechinus quadriserialis* Wright.**

Text-fig. 217, p. 191; Plate 29, fig. 1; Plate 30, figs. 1-7.

Palaecechinus quadriserialis Wright, 1865, pp. 62, 63, and 88, 89, Plate 3, figs. 1a-1c; Pomel, 1883, p. 114; Lambert and Thiéry, 1910, p. 119.

Palaecechinus ellipticus Baily, 1865a, p. 217; 1865c, p. 65-67, and 88, Plate 3, figs. 2a, 2b; Quenstedt, 1875, p. 380, Plate 75, fig. 42; (non *Palaecechinus ellipticus* Duncan, 1889, see *Lovenechinus lacazei* this memoir, pp. 326, 329, Plate 36, figs. 1, 3).

Palaecechinus ellipticus (pars) Lovén, 1874, p. 41.

Palaecechinus quadriserialis Lovén, 1874, p. 41.

Rhocchinus quadriserialis Duncan, 1889, p. 205; Tornquist, 1897, p. 755; Klem, 1904, p. 30.

Rhocchinus quadrangularis (by clerical error) Jackson, 1896, table facing p. 242.

¹ A number of species which have been referred to the genus *Palaecechinus* but not known well enough to intercalate in the systematic series, or species of which no description has been published, are taken up later. These are *Palaecechinus (?) konigii* M'Coy, *Palaecechinus (?) regnyi* nom. nov. (= *P. konincki* Julien), *Palaecechinus robineti* Julien, and *Rhocchinus sp.* (used in the sense of *Palaecechinus*), considered under *Incertae Sedis*, p. 450. Also *Palaecechinus agassizi*, *P. carpenteri*, *P. loveni*, all of Dollo and Buisseret, considered under *Nomina Nuda*, p. 457; and *Palaecechinus sp.* Mitchell, considered under *Palaeozoic Forms Incorrectly Referred to Echini*, p. 458.

The test is high, elliptical; according to Wright, the type measures 51 mm. in height and 38 mm. in diameter. The British Museum specimen measures about 42 mm. in height and about 34 mm. in diameter through the mid-zone. The ambulacra measure 4.5 mm. in width near the mid-zone, and the interambulacra 17 mm. in width.

The ambulacra are narrow with two columns of low plates in each area, all of which meet the middle of the area and the interambulacrum; about five ambulacral plates equal the height of an adambulacral; pore-pairs are uniserial. Ambulacral plates bevel over the adradials on the marginal sutures. The interambulacra are wide with four columns of plates at the mid-zone in each area. There are two plates in the basicoronal row, above which the added columns come in early, and there is no loss of parts by senescent growth dorsally. Plates of the test are moderately thick, bearing numerous secondary tubercles only; spines are not known. Oculars are all insert, imperforate, and cover the ambulacra and laterally in part the interambulacra on either side. Genitals are high and wide, each known having three genital pores. This species is similar to *ellipticus* in form, but differs in having four instead of five columns of interambulacral plates. It is also a much smaller species. Baily (1865a, 1865c) described a specimen of this species as *P. ellipticus*, as he felt that the difference in the number of interambulacral columns did not entitle it to specific distinction. A difference in the number of interambulacral columns is a valid differential character, and I think these two species should be maintained. Baily's use of *ellipticus* for *quadrisesialis* was quoted by Lovén, and his figure was copied by Quenstedt as given in the synonymy.

Lower Carboniferous Limestone, Middleton, County Cork, Ireland. This is the locality of the type, but I do not know where the specimen is; the specimen figured by Baily is from Bettyville, near Crome, County Limerick, Ireland; the specimen in the British Museum Collection E 193 is from Rathkeale, County Limerick, Ireland; Hook Head, Ireland, Museum für Naturkunde, Berlin, a cast of this specimen is in the Museum of Comparative Zoölogy Collection 3,117.

The British Museum specimen of this species is well preserved, so that it is represented spread out by the Lovén method in Plate 30, fig. 3. It agrees entirely with Wright's description and excellent figures of the species. It is preserved without distortion and free from all matrix. In parts the plates are in place, as shown in Plate 30, figs. 1, 3, 4, and at these parts the tubercles are shown. Much of the rest is preserved as an internal mold of the plates by the filling matrix, and in the figures is represented in simple outline; again, part is restored as indicated by dotted lines. There are two plates in the basicoronal row in each interambulacrum and three plates in the second row. In all areas excepting C the initial plate of column 3 is hexagonal as usual, as it is in contact with the initial plate of column 4. But in area C the initial plate of column 3 is pentagonal, as the initial plate of column 4 is in the second row above, instead of the next row. Column 4 originates in the third row in four areas with a pentagonal

plate that impinges on the initial plate of column 3, and in virtue of its one side lacking, a compensating side is added to this plate making it hexagonal (p. 68). In area C, however, column 4 originates in the fourth row, with the result that the plate on its ventral border is heptagonal (partially restored as indicated by dotted lines), and the initial plate of column 3 is pentagonal. A similar case is shown in area C of *Lovenechinus septies* (Plate 45, fig. 1) but it is of rare occurrence, as column 4 almost always originates in the next row after column 3. Column 4 originates on the right of the center in areas A, C, and I, but on the left of the center in areas E and G, with some consequent readjustment of plates (compare *Archaeocidaris*, Plate 9, figs. 6-8; text-fig. 239 *bis*, p. 264). Above the fourth row no new columns are added, but all four columns extend to the apical disc where the youngest plates on either side are in contact with the oculars. Two oculars are in place, are widely insert, and imperforate. The three genitals are high, wide, and have each three genital pores. All bear secondary tubercles as shown in Plate 30, fig. 4, in which the absent plates are restored, as indicated by dotted lines.

I am under obligation to Dr. Bather for the photograph of this specimen which is reproduced on Plate 29, fig. 1.

****Palaeechinus ellipticus* M'Coy.**

Plate 29, fig. 2; Plate 30, figs. 8-10.

Palaeochinus ellipticus M'Coy, 1844, p. 172, figs. 3a-3d; Desor, 1858, p. 158; (?) Tornquist, 1893, p. 103; (pars) Klem, 1904, p. 31; Lambert and Thiéry, 1910, p. 119.

Echinocrinus ellipticus d'Orbigny, 1849, p. 126, text-fig. 278.

Palaeocidaris (Echinocrinus) ellipticus Vogt, 1854, p. 332, text-figs. 212-214.

Non *Palaeochinus ellipticus* Bailey, 1865a, p. 217; non 1865e, pp. 65-67, Plate 3, figs. 2a, 2b; non Quenstedt, 1875, p. 380, Plate 75, fig. 42.¹

Palaeochinus ellipticus (pars) Lovén, 1874, p. 41.¹

Non *Palaeochinus ellipticus* Duncan, 1889, p. 200, text-fig. viii; (see p. 308, and this memoir, pp. 326, 329, where Duncan's specimen is referred to *Lovenechinus lacazei*).

Non *Paleochinus ellipticus* Tornquist, 1897, p. 739; non *Maccoya ellipticus* Lambert and Thiéry, 1910, p. 119 (both of these names are based on Duncan's 1889, p. 200, text-fig. viii, *Palaeochinus ellipticus*, here referred to *Lovenechinus lacazei* as above stated).

The test is high and elliptical, 51 mm. high, 41 mm. in diameter, width of the ambulacrum at the mid-zone 4 mm., width of the interambulacrum 22.5 mm. About seven and one-half ambulacral plates equal the height of an adambulacral. The observations were made on M'Coy's type specimen in Dublin, which I studied through the kindness of Dr. Scharff, who also kindly supplied me with a cast and the photograph here reproduced.

The ambulacra are narrow, composed in each area of two columns of low plates, all of which

¹ These several references to *Palaeochinus ellipticus* as a synonym are in regard to a specimen that Bailey described as that species but is here referred to *P. quadriserialis* (pp. 305, 306).

are primaries, meeting the middle of the area and the interambulacral areas. The pore-pairs are uniserial (Plate 30, fig. 10). M'Coy was quite correct in describing the ambulacral structure as he did, and Duncan (1889, p. 200, text-fig. viii) was mistaken when he claimed for this species the structure of four columns of ambulacral plates and a biserial arrangement of pores in an area. Duncan's specimen is in the Museum of Practical Geology Collection 16,301; it has no connection with *Palaeochinus ellipticus*, and is here described as *Lovenechinus lacazei* (footnote p. 303; p. 329, Plate 36, figs. 1-3).

The interambulacrum of *ellipticus* has five columns of plates at the mid-zone, as shown in two areas of the type; the adambulacral plates are pentagonal, the others hexagonal. In one area (Plate 30, fig. 8) there are two plates in the basicoronal row, three in the second, four in the third, and five in the fifth row. Ambulacral and interambulacral plates alike have numerous secondary tubercles. The holotype is the only specimen of the species known to me, and the numerous figures in text-books are taken from M'Coy's original figures, since when it has not been published from direct observations. This species is the type of the genus as selected by Lambert and Thiéry (1910, p. 119).

Lower Carboniferous, Millicent, County Clare, Ireland; holotype in the Griffith Collection, Science and Arts Museum, Dublin; a cast of this specimen is in the Museum of Comparative Zoölogy Collection 3,115.

The specimen referred to *Palaeochinus ellipticus* by Baily (1865a, 1865c) and by Quenstedt who copied Baily's figure, has four columns of interambulacral plates, and is here referred to *Palaeochinus quadriserialis*. The specimen referred to *P. ellipticus* by Duncan (1889, p. 200) is here referred to *Lovenechinus lacazei* (p. 329) as above stated.

****Palaeochinus elegans* M'Coy.**

Text-figs. 9, p. 54; 15, p. 59; 237, p. 231; Plate 29, figs. 3, 4, 6; Plate 30, fig. 11; Plate 31, figs. 1-5.

Palaeochinus elegans M'Coy, 1844, p. 172, Plate 24, figs. 2a-2d; Roemer, 1852-'54, p. 287, Plate 4, figs. 1a-1d; Desor, 1858, p. 158; Baily, 1865, pp. 44, 45; 1865b, pp. 63-65, and 67, Plate 4, figs. A-E; Quenstedt, 1875, p. 380, Plate 75, figs. 39, 43; Baily, 1875, p. lxxviii, Plate 36, figs. 11a-11d; A. Agassiz, 1892, p. 73, Plate 29, fig. 2; Tornquist, 1893, p. 103; Lambert and Thiéry, 1910, p. 119.

Palaeochinus elegans Lovén, 1874, p. 41.

Palaeochinus [*elegans*] Etheridge, 1874, p. 311, Plate 3, fig. 3.

Rhoechinus elegans Duncan, 1889, p. 205; Jackson, 1896, table facing p. 242 (but not text-fig. 1, p. 205, and not Plate 7, fig. 40¹); Tornquist, 1897, p. 757, Plate 21, figs. 6, 7; Klem, 1904, p. 28; Fraipont, 1904, p. 10, Plate 2, fig. 9.

I had the opportunity to study M'Coy's type of this species and also other good specimens as described in some detail below; from all of these the species description is made up. Test

¹ These figures are referable to *Maccoya intermedia*, see p. 314.

spheroidal, in the type somewhat crushed, but it measures about 55 mm. in width, the ambulacrum at the mid-zone is 5 mm. in width, the interambulacrum 24 mm. in width.

The ambulacra are narrow with two columns of low plates in each area. The plates are all primaries, meeting the interambulacra and the middle of the ambulacra throughout the areas; pore-pairs uniserial. Five or six ambulacral plates equal the height of an adambulacral. There are five columns of interambulacral plates at the mid-zone in each area in all specimens seen. The ventral portion of the test unknown, but it is doubtless similar to that of *Palaeochinus quadriserialis*, Plate 30, fig. 3. Ambulacral and interambulacral plates with numerous secondary tubercles which bear small spines, swollen at the base, tapering to the tip, all of similar size and measuring about 1.1 mm. in length. Oculars are insert, imperforate (not with two pores as described by Baily); genitals are wide, high, with three or more genital pores each. The periproct in the type is remarkably well preserved, with many small angular plates like those of modern cidarids. The apical disc and periproct figured by Baily (1865b, Plate 4, fig. B) were freely and in some respects incorrectly restored (p. 363).

Lower Carboniferous, Hook Head, County Wexford, Ireland; slab with two specimens including the holotype in the Griffith Collection, Science and Arts Museum, Dublin; a cast of this specimen is in the Museum of Comparative Zoölogy Collection 3,116; same locality, Museum of Practical Geology, London, 6,580; Putig, Germany (Törnquist); Marbre Noir de Dinant, Belgium (Fraipont).

The most nearly complete specimen known is M'Coy's type, which is one of two specimens of this species on a slab in the Dublin Museum. I had the pleasure of studying it there and in addition, Dr. Scharff had the great kindness to bring it with him to America in order to give me further opportunity for inspection. Besides the two specimens of *Palaeochinus elegans*, this choice slab bears a specimen of *Perischodomus biserialis* (Plate 29, fig. 5). Baily (1865b, p. 63) in his observations says that there are three specimens of *Palaeochinus elegans*, but this is a mistake, the specimens being as stated. One of the specimens of *P. elegans* is better than the other, and is the basis of M'Coy's and Baily's observations. Ambulacra D and J extend directly to the oculars, and F is preserved in part. The ambulacra bevel over the adambulacrals laterally (Plate 31, fig. 3). Interambulacrum E is the most nearly complete and shows five columns of plates, but dorsally, column 5 (Plate 31, fig. 4) drops out before reaching the apical disc. The surface of the plates is in part worn, but I have shown the small secondary tubercles in the parts where such occur. Interambulacra E and I (Plate 31, fig. 4) evidently have each five columns of plates, although one of the adradial columns is partially wanting in each of these areas. Dorsally four oculars are in place, but ocular F is imperfect and not shaded in the figure. The oculars are all insert, covering the ambulacra and laterally in part the interambulacra on either side. The oculars are imperforate, and Baily's (1865b, Plate 4, fig. B) figure showing two pores in each plate was a mistake. I cannot see how it occurred.

It has proved unfortunate as Baily's figure has been extensively copied as a typical apical disc for the Palaeozoic. The genitals are high and wide; E and G have each three pores, but C apparently has four pores and A has five genital pores as seen in Plate 29, figs. 3, 6. By oversight, in Plate 31, figs. 1 and 4, only three instead of five pores are shown in genital A. A number of periproctal plates are in place, they are polygonal in outline, and doubtless filled the area, as shown by Baily in his reconstruction (pp. 89, 173). The second specimen on this slab is much less complete, but shows two columns of ambulacral plates in an area with pore-pairs uniserial, also five columns of plates in one interambulacral area.

In the specimen in the Museum of Practical Geology (Plate 30, fig. 11; Plate 31, fig. 5) there are two columns of plates in each ambulacral area with pore-pairs superposed, and five columns of plates in an interambulacral area. A number of spines are in place, as described above, and these are of interest as the only ones yet known in the genus.

The specimen from Dinant, Belgium, figured by Fraipont, is of about the same size as the type, and has five columns of plates in each interambulacral area.

***Palaeechinus (?) minor** sp. nov.

Plate 29, figs. 7, 8; Plate 31, fig. 6; Plate 32, fig. 7.

The specimens of this species are all internal sandstone molds, so that surface characters are unknown. Test nearly or quite spherical. The holotype (Plate 29, fig. 7) measures 36 mm. in height, and 35 mm. in diameter, but it is somewhat distorted. The Museum of Comparative Zoölogy's specimen (Plate 29, fig. 8) is perfect in form and measures 37 mm. both in height and diameter through the mid-zone. It is one of the very few Echini which have been found to be actually spherical.

The ambulacra are narrow with two columns of low plates in each area. About five ambulacral plates equal the height of an interambulacral; pore-pairs are uniserial. While this species is apparently a *Palaeechinus*, it must be remembered, as I have shown (p. 60), that in *Maccoya* the plates on the proximal side are all primary in character and pore-pairs are uniserial, while on the external or distal side of the same plates the character is primary, and occluded plates and pore-pairs are biserial (Plate 33, figs. 4, 5, 7, 8). As the views of *P. minor* are all molds of the interior, it may therefore later prove that the species is really referable to *Maccoya*, but whichever the genus, the interambulacral features entitle it to specific separation from other species of *Palaeechinus* and from known American forms of *Maccoya*.

In the holotype there are six columns of interambulacral plates in an area (Plate 31, fig. 6). The figure (partially restored ventrally as shown by dotted lines) is made up from two areas. Dorsally columns 6 and 3 drop out, indicating senescence, and a full grown specimen. The oculars are all insert, and genitals are high, with three pores each.

In the Museum of Comparative Zoölogy's specimen (Plate 29, fig. 8) there are six columns of plates in four interambulacral areas, but only five columns in one area. Oculars are all insert. The apical disc measures 8 mm. in diameter equaling about 21% of the diameter of the test. This is relatively larger than in adults of most species of the family, but is the same proportion as in the young of *Lovenechinus missouriensis* (p. 342). In Mr. Kirk's specimen (Plate 32, fig. 7) there are six columns of plates in all five interambulacral areas. This species is the only one in America at present referable to *Palaeochinus* proper.

Base of the Burlington Limestone, Lower Carboniferous, Burlington, Iowa, holotype, University of Chicago Collection 9,054; paratypes, Museum of Comparative Zoölogy Collection 3,051; E. Kirk Collection, one specimen; F. Springer Collection, two specimens.

MACCOYA Pomel.

MacCoya Pomel, 1869, p. xlv.

Wrightia Pomel, 1879, p. xlv (printed by error *Wrightia*); Pomel, 1883, p. 115; non Agassiz, 1862, *Acalephs*, *Diseophora*, p. 354.

Muccoya Pomel, 1883, p. 115; (pars) Lambert and Thiéry, 1910, p. 119.

Wrightella Pomel, 1883, p. 115; Lambert and Thiéry, 1910, p. 120.

Non *Ericchinus* Pomel, 1883, p. 114 (see footnotes, pp. 303, 312, 326).

Non *Typhlechinus* Neumayr, 1889, p. 362, text-fig. 82c; 1890, p. 85 (see footnotes, pp. 312, 326).

Palaeochinus (pars) Dunean, 1889, p. 205; 1889a, p. 13; (pars) Jackson, 1896, pp. 200, 239 (see this memoir, p. 303).

Palaeochinus (pars) Klem, 1904, p. 31; (pars) Lambert and Thiéry, 1910, p. 119.

Palcchinus (pars) Tornquist, 1897, p. 735.

The test is spheroidal, ambulacra are narrow, composed of two columns of plates in each area, all plates meet the middle of the area, but at the mid-zone alternate plates are primaries, meeting the interambulacral areas and enlarged marginally, while the plates between are narrowed laterally and are nearly or quite cut off from contact with the interambulacra by the marginal enlargement of their fellows (Plate 34, fig. 2). There are two pores to each plate¹ and the pore-pairs are biserial. All this is as seen on the exterior; on the interior at the mid-zone and throughout the area all plates cross the half-areas and pore-pairs are uniserial (Plate 33, figs. 4, 5, 7, 8). As seen from the exterior, ventrally the ambulacral plates built in youth as a stage in development, and also young plates dorsally near the apical disc, as a localized stage, are all typical primaries crossing the half-areas and with pore-pairs uniserial. This is like the condition characteristic of the mid-zone in the lower genus *Palaeochinus*.

The interambulacra in the known species have in each area from four to eight, or exceptionally nine columns of plates at or above the mid-zone. The peristome and lanterns are

¹ Miss Klem (1904, p. 31) says of *Palaeochinus* [Maccoya], four pores in each ambulacral plate. This is a character not known in the genus nor in any Palaeozoic echinoid.

unknown to me in the genus; but Duncan (1889a, p. 14) says the teeth are grooved. Oculars are all insert, or one or more to all may be exsert, being shut out from contact with the periproct by the contact of the associated genitals. Genitals are high and wide with several pores each. The periproct is plated with many small thick angular plates similar to those of a Recent cidarid.

The type species of the genus is *M. gigas* (M'Coy) from the Lower Carboniferous of Europe.

Maccoya as a genus occupies a place structurally intermediate as regards the ambulacrum between *Palaeochinus* and *Lovenechinus*. The youthful and dorsal localized stages of Maccoya are like *Palaeochinus* at the mid-zone, and also the character of the plates at the mid-zone of Maccoya is like the secondary youthful and dorsal localized stages of *Lovenechinus* as set forth in the diagram (text-fig. 237, p. 231).

Pomel's *Wrightella* with *Palechinus phillipsiae* Forbes as the type I do not consider distinct as it has essentially the same structure of the ambulacrum as Maccoya.¹

Duncan's *Palaeochinus* used in his restricted sense was intended to cover much the same ground as Pomel's Maccoya, but was more inclusive and embraced some structural types which I refer to *Lovenechinus* (see pp. 303, 304 and footnote, p. 303). He apparently made a mistake in taking for *Palaeochinus*, species which were not covered by M'Coy's original description, when there were species that did fall within those limits (Duncan's *Rhoechinus*). At all events Pomel had priority as first reviser of the old genus *Palaeochinus* M'Coy.

Key to the Species of Maccoya.

Four columns of plates in each interambulacral area (America)

M. burlingtonensis (Meek and Worthen), p. 312.

Four columns of plates in each interambulacral area (Europe) *M. intermedia* (Keeping), p. 314.

Five (?) columns of plates in an interambulacral area *M. phillipsiae* (Forbes), p. 316.

Five to six or seven columns of plates in each interambulacral area, test robust, plates of moderate size

M. sphaericus (M'Coy), p. 317.

Six (?) columns of plates in an interambulacral area, the plates very wide and high

M. gigas (M'Coy), p. 321.

Seven to eight, or exceptionally in part nine, columns of plates in each interambulacral area

M. gracilis (Meek and Worthen), p. 323.

* **Maccoya burlingtonensis** (Meek and Worthen).

Text-figs. 10, p. 54; 16, p. 59; 237, p. 231; Plate 32, figs. 1-3; Plate 33, figs. 1-5.

Palaeochinus burlingtonensis Meek and Worthen, 1860, p. 396; 1866, pp. 230, 231, text-fig. 23, Plate 16, figs. 3a-3c; A. Agassiz, 1874, pp. 648, 649, text-fig. 7; Keyes, 1895, p. 180.

¹ Pomel's *Eriechinus* and Neumayr's *Typhlechinus* were both based on what de Koninck described as *Palaeochinus sphaericus*, but it was a mistaken identification and is considered here under *Lovenechinus lacazei* (Julien), pp. 330-334, text-figs. 240-243; Plate 35, fig. 7. See footnotes pp. 303, 326.

Palaeochinus burlingtonensis Lovén, 1874, p. 41; Duncan, 1889, p. 205.

Maccoya burlingtonensis Pomel, 1883, p. 115; Lambert and Thiéry, 1910, p. 119.

Rhocchinus burlingtonensis Jackson, 1896, p. 203, Plate 7, fig. 37; Tornquist, 1897, p. 762; Klem, 1904, p. 27.

The test is spheroidal. In Mr. Kirk's specimen (Plate 32, fig. 2) the ambulacrum is 5 mm. wide, interambulacrum 18 mm. wide at the mid-zone. From these measurements the circumference would be about 115 mm., the diameter about 37 mm., and the height as estimated is very nearly the same. A specimen in the Museum of Comparative Zoölogy, no. 3,011, is complete in form and very nearly spherical. It is about 36 mm. in diameter at the mid-zone and a trifle more than that when measured through the poles. The ambulacrum is 5.5 mm. wide and the interambulacrum about 17 mm. wide at the mid-zone.

The ambulacra are narrow, with two columns of low plates in each area. All ambulacral plates meet the middle of the area, but at the mid-zone, on the exterior, alternate plates are primaries, reaching and enlarged at their contact with the interambulacrum; or plates are occluded, being narrowed and cut off from interambulacral contact. The pore-pairs at the mid-zone are biserial (Plate 33, fig. 2). While this is the character of the exterior, on the interior a different and more primitive condition exists, for here all plates cross the half-area without marginal modification, and pore-pairs are uniserial, as seen in external and internal views of the very same plates (Plate 33, figs. 4, 5). On the exterior, the plates ventrally, built in the youth of the individual, and also dorsally the young plates, as a localized stage, are all simple primaries, completely crossing the half-area and with pore-pairs uniserial (Plate 33, figs. 1, 2). This simplicity of plates built in youth, of young plates dorsally, and of plates at the mid-zone seen from within, is directly comparable to the simplicity of all plates in the more primitive genus *Palaeochinus* (p. 60). Ambulacral plates bevel over the adambulacra on the marginal suture.

There are four columns of plates in each interambulacral area at the mid-zone, as shown in twelve specimens. Ventrally, as seen clearly in one of Mr. Springer's fine series of specimens (Plate 32, fig. 1; Plate 33, fig. 1), there are two plates in the basicoronal row, three in the second, and four in the third row, above which no more columns are added. The same structure is shown ventrally in a large specimen in the Museum of Comparative Zoölogy (3,194), only in this individual the initial pentagon of column 4 is on the left of the center in the third row instead of on the right of the center. It is interesting to see that in this species with only four columns of interambulacral plates, as also in *Palaeochinus quadriserialis* (Plate 30, fig. 3), that the fourth column originates in the third row from the peristome as it does throughout the family with very rare exceptions. In *burlingtonensis* the adradial plates are pentagonal, all others hexagonal, excepting ventrally where new columns are coming in. Ambulacral and interambulacral plates alike bear numerous small secondary tubercles, shown beautifully in Mr. Kirk's choice specimen (Plate 32, fig. 2). Meek and Worthen figure a spine enlarged showing that it is swollen at the base, slender, tapering, and, judging from the figure, about 4 mm. in length,

which is about the usual size in this family. The oculars and genitals are shown well in one specimen in the Museum of Comparative Zoölogy (3,196). In this specimen, which is an internal view, three oculars are in place, all are insert and adorally cover the ambulaera and laterally the interambulaera in part on either side. One of the two genitals has three pores, the second genital is obscure on this point.

Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa, F. Springer Collection, eight specimens; Museum of Comparative Zoölogy Collection 3,011, 3,047-3,050 and 3,194-3,196; E. Kirk Collection. The holotype is said to be in the Worthen Collection, now in the University of Illinois, at Urbana, Illinois.

****Maccoya intermedia* (Keeping).**

Plate 33, figs. 6-12; Plate 34, figs. 1-3.

Palacchinus (?) *intermedius* Keeping, 1876, p. 37, Plate 3, figs. 9-11.

Palacchinus intermedius Duncan, 1889, p. 203, text-figs. ix, x.

Rhocchinus elegans (by error of identification) Jackson, 1896, text-fig. 1, pp. 191, 205, Plate 7, fig. 40.

Palechinus intermedius Tornquist, 1897, p. 739.

Palacchinus intermedius Klem, 1904, p. 33; Lambert and Thiéry, 1910, p. 119.

I have had the privilege of studying fine material of this species at Cambridge, England, and at Munich, Dublin, and London. Test spheroidal. Ambulaera narrow, with two columns of low plates, all of which meet the middle of the area. On the exterior of the test at the mid-zone alternate plates are primaries, enlarged on the margin, and four of these primaries equal the height of an adambulacral plate; the intermediate plates are narrowed marginally and cut off from interambulacral contact by the enlargement of their adjacent plates on either side, and therefore are occluded. Pore-pairs are biserial, the outer pores of the occluded plates falling in line with the inner pores of the primary plates (Plate 33, figs. 6, 7). As seen from the interior all ambulacral plates cross the half-area completely and pore-pairs are uniserial (Plate 33, figs. 8, 9; Plate 34, fig. 3), (p. 60).

In the interambulaera there are four columns of hexagonal median and pentagonal adradial plates in each area, as ascertained in six specimens. Keeping was evidently mistaken in thinking that there might be five columns, and his doubt on the point is indicated by the fact that he queried the statement. Developmental details of the interambulaera are not known, as all specimens are wanting ventrally, but they are doubtless the same as shown in *burlingtonensis*. Ambulacral and interambulacral plates bear numerous small secondary tubercles, but the spines are unknown. Ambulacral plates bevel over the interambulacra on the adradial sutures as in all of this family, but the sides of the plates otherwise are as nearly parallel as is possible in a curved test, and there is no imbrication. Keeping was certainly mistaken in saying that

the interambulacral plates overlap from below upwards [imbricate aborally] and that the ambulacra overlap in the opposite direction. Except for the bevel on the adradial suture I have seen no imbrication of ambulacral or interambulacral plates in this or any other species in this family.

The apical disc is relatively small. Ocular plates may be insert, or in one specimen one ocular is exsert, and in another all oculars are exsert (Plate 33, figs. 11, 12). It is very rare for oculars to be exsert in the family (p. 89). The genitals are wide and high, with several up to five genital pores each. The periproctal plates are unknown. This species seems to be indistinguishable from *M. burlingtonensis*, but in view of the incomplete knowledge of the structure and the wide geographical separation it seems best to maintain both species.

Lower Carboniferous, Hook Head, County Wexford, Ireland, several specimens, including the holotype, Sedgwick Museum, Cambridge, England; four specimens, Munich Museum; two specimens, Trinity College, Dublin; Museum of Practical Geology, London, Collection 16,302; Museum of Comparative Zoölogy Collection 3,002.

Of the Munich specimens of this species, one (Plate 33, figs. 6-9) has four columns of plates in one interambulacral area, and also shows the tubercles clearly. The ambulacral detail is clear on the surface with alternate primary and occluded plates, but in a portion showing the interior the plates at this area are all primary in character with pore-pairs uniserial. Another Munich specimen (Plate 34, fig. 1) is worn, but shows the form of the test quite well. There are four columns of plates in two interambulacral areas. In area C in the middle line dorsally there is in addition a single plate which may be considered a tendency toward an extra column as a progressive variation. The only ocular preserved is insert.

In the Sedgwick Museum, Cambridge, England, there are seven specimens, including Keeping's holotype. Four of these have four columns of interambulacral plates in an area. The type specimen (Plate 33, fig. 10, after Keeping) is most interesting. It has two columns of interambulacral plates in place and displaced plates representing a third column. The left adradial column is wanting in the more nearly complete area. The ambulacrum is slightly pulled away from the adradial plates on the marginal suture, and reveals the structure graphically (Plate 34, figs. 2, 3). To understand it one must remember that ambulacral plates bevel over the adradials, so that the marginal sutural face of the adradials is an inclined, not a vertical face. On the exterior or distal aspect of this face four facets appear for the reception of the primary ambulacral plates, and these facets in passing proximally become much narrower. On the proximal face of the suture, between the narrowed facets, are seen other alternating facets which receive the impact of the occluded ambulacral plates. This relation is perfectly clear, for on the exterior of the specimen (Plate 34, fig. 2) ambulacral plates are alternately primary and occluded, and pore-pairs biserial, whereas on the interior, as shown in part (Plate 34, fig. 3), ambulacral plates all cross the half-area and pore-pairs are uniserial. Because of this structure it seems that from a single adradial plate one could determine the genus.

Another of the Cambridge specimens (Plate 33, fig. 11) shows four columns of plates in three interambulacral areas; all five oculars are in place, four are insert as usual in the family, but one is excluded from the periproct by the contact of two genitals. The oculars cover the ambulacra and laterally the interambulacra in part on either side, the youngest interambulacral plates being in contact with the oculars. The genitals are high, wide, and three of them have three pores each; the others, two or no pores, but the pores were probably obliterated in fossilization. Still another specimen (Plate 33, fig. 12) has all the oculars in place, and they are all exsert, this as above stated being the only case seen in the family. It is a variation toward the character which is the dominant one in Mesozoic regular Echini, and the youthful (sometimes adult) character of all Recent regular Echini. The genitals are very wide and high and have three or five pores each. Of the two specimens in Trinity College, Dublin, one has four columns of interambulacral plates in an area and both show the typical character of the ambulacrum.

The specimen in the Museum of Practical Geology Collection 16,302, shows the ambulacrum and part of an interambulacrum. It is the original of Duncan's (1889) text-fig. ix, p. 206.

***Maccoya phillipsiae* (Forbes).**

Plate 33, figs. 13, 14.

Palaechinus phillipsiae Forbes, 1848, pp. 302, 384, Plate 29, figs. 1, 1a; Tornquist, 1897, p. 739.

Palaechinus phillipsiae Roemer, 1852-'54, p. 288; Desor, 1858, p. 159; Quenstedt, 1875, p. 379, Plate 75, fig. 41; Klem, 1904, p. 35.

Wrightia phillipsiae (printed by error *Wrightia*) Pomel, 1869, p. xlv.

Palaechinus phillipsiae Lovén, 1874, p. 41; Duncan, 1889, p. 205.

Wrightella phillipsiae Pomel, 1883, p. 115; Lambert and Thiéry, 1910, p. 120.

Form of test unknown, but probably spheroidal. Ambulacra are narrow, with two columns of low plates, all of which meet the middle of the area, but are alternately primaries which meet the interambulacra and ocluded plates which fall far short of the same. Pore-pairs biserial. The specimen is badly preserved, and in Forbes's reconstruction (my Plate 33, fig. 14) the ocluded plates are probably too narrow and the pores of the same too near the middle of the area. There are three columns of interambulacral plates in place, and Forbes assumed five columns for the area as shown in the reconstruction. This may or may not be correct.

Forbes says, found in conglomerate under the Worcester Beacon by Miss Phillips, and gives the horizon as Silurian. Forbes (1848, p. 302) considered the age of this conglomerate as Caradoc, which is Ordovician (Lower Silurian), but with later study it is found to be Llandovery, which is the base of the Silurian. Whether the specimen described came from this horizon is open to doubt. A cast of the type specimen is in the Museum of Practical Geology Collection 16,359. The location of the type I do not know.

This species is the type of Pomel's *Wrightella*, but its characters fit very well into the genus *Maccoya*, and there seems no occasion for maintaining a separate genus for its reception.

Llandovery, Silurian (?), in conglomerate under the Worcester Beacon, England.

****Maccoya sphaerica* (M'Coy).**

Plate 32, figs. 4, 5; Plate 34, figs. 4-10.

Palacchinus sphaericus M'Coy, 1844, p. 172, Plate 24, figs. 5a-5c; Desor, 1858, p. 158; Dujardin and Hupé, 1862, p. 464; Baily, 1865c, p. 89; Keeping, 1876, p. 38; Smith, 1901, p. 509; Lambert and Thiéry, 1910, p. 119.

Non *Palacchinus sphaericus* Koninek, 1869, p. 546, Plate [not numbered], fig. 1; non Koninek, 1870, p. 259, Plate 7, fig. 1; non Baily, 1874, p. 41; non Zittel, 1879, p. 484; (pars) Lovén, 1874, p. 41; non Neumayr, 1881, p. 151; non A. Agassiz, 1892, p. 73; (pars) Klem, 1904, p. 35.¹

Palaechinus sphaericus (pars) Lovén, 1874, p. 41; Duncan, 1889, p. 196, text-figs. ii-vii.

Non *Ericchinus sphaericus* Pomel, 1883, p. 114.¹

Non *Typhlechinus sphaericus* Neumayr, 1889, p. 362, text-fig. 82c.¹

Non *Palaechinus sphaericus* Tornquist, 1897, p. 736.¹

Palacchinus sphericus (pars) Klem, 1904, pp. 34, 35.

M'Coy's type of this species is in Dublin (Plate 32, fig. 5; Plate 34, fig. 7). In addition, there are three specimens in the British Museum (Plate 32, fig. 4; Plate 34, figs. 4-6), three in the Sedgwick Museum, Cambridge, England, and one in the Strassburg Museum (Plate 34, figs. 8, 9), all of which are similar and are referred to *sphaerica*.

M'Coy's type is almost spherical, but the height has to be estimated, as the dorsal part is covered by a lump of the original matrix. Of this specimen the circumference at the mid-zone measures 203 mm.; the diameter, in the same plane, 65 mm.; height, approximately 65 mm.; width of ambulaerum B at the mid-zone, 6 mm.; width of an interambulaerum about 34 mm.

Ambulaera are narrow, rounded up in the center, so that the greatest elevation is in line with the curvature of the interambulaera. Ambulaerum B is the only one in which the surface of the plates is shown, other areas being internal molds for the most part. The details of plate structure are difficult to ascertain, but Plate 34, fig. 7, was drawn at the point marked X in Plate 32, fig. 5. As seen here, all ambulacral plates meet the middle of the area, but against the interambulaerum alternate plates are primaries, marginally expanded, and intermediate plates are narrowed and just cut off from contact with the interambulaerum. Pore-pairs are biserial. In the British Museum and other specimens all ambulacral plates usually meet the interambulaerum, though alternate plates are narrowed, and pore-pairs are biserial.

¹ These several references in the above paragraphs are all in regard to the specimen described by de Koninek as *Palaechinus sphaericus* from Kirkby Stephen, Westmoreland, England. The specimen has a very different structure from that of *Maccoya sphaerica* (M'Coy), and likewise different from that of the genera *Palaechinus* and *Maccoya*. It is here described as *Lovenechinus lacazei* (Julien), footnotes, pp. 303, 312, 326, also pp. 330-334, text-figs. 240-243; Plate 35, fig. 7.

In the type there are six or seven columns of plates in an interambulacral area at the mid-zone. In area A there are six columns, and below the mid-zone the introduction of the fifth and sixth columns is seen, both originating as usual with a pentagonal plate. By this means the specimen was oriented, and it will be noticed that the orientation of my figure is the reverse of that given by M'Coy. In this area, A, the six columns extend dorsally to the covering matrix. In interambulacrum C there are seven columns at the mid-zone. The seventh column consists of four plates only, on one of which the letter C occurs in Plate 32, fig. 5. Ventrally and dorsally to the seventh there are six columns in this area. Areas E and G are imperfect, for the most part internal molds, and the full number of columns was not ascertained. Interambulacrum I is also an internal mold, but the impress of six columns of plates was clearly ascertained at the mid-zone. In one of the British Museum specimens (E 3,652) there are seven columns of plates in the only interambulacral area clearly preserved. Of two other British Museum specimens (E 361) on a single slab, one has five columns of plates in all five interambulacral areas (Plate 32, fig. 4), whereas the other has five columns in one area, but six in two other areas.

On account of the matrix covering the dorsal area, the features of this part are unknown in the type. In the British Museum specimen (Plate 34, fig. 6), the apical disc is small, the oculars are all insert, genitals wide, low (pores not visible), and the periproct has numerous small angular plates as usual in the Palaeozoic.

M'Coy's type is in Trinity College Museum, Dublin, where I studied it through the kindness of Professor Joly. There is no locality given, but it bears the label, "Presented by Dr. A. N. Fox, Staff Assistant Surgeon, 1 Nov., 1867." For several years earlier it had been in the possession of the Rev. S. W. Fox. According to Bailly (1865c, p. 89) the specimen was supposed to have come from the limestone of the County Kildare, but that was not certain. A plaster cast of this valuable specimen is in the Museum of Practical Geology in London, and another in the Museum of Comparative Zoölogy.

Confusion has been introduced as to the structure of this species by de Koninck's (1870) description of a specimen which he referred to *Palaeochinus sphaericus* M'Coy. Through the great kindness of my friend Dr. F. A. Bather, the specimen was borrowed from the York Museum, and it proves that the description was incorrect in several particulars. The specimen is not a *Maccoya sphaerica*, and does not even belong to the genus *Maccoya*, having a very different ambulacral structure. It is here referred to *Lovenechinus lacazei* (text-figs. 240-243, p. 331; Plate 35, fig. 7). From this it occurs that statements in regard to the absence of oculars (entirely wrong), structure of the genital plates (also incorrect), and the number of interambulacral columns ascribed to *sphaerica*, as far as based on de Koninck's observations, are erroneous (footnote, p. 303).

Lower Carboniferous, probably County Kildare, Ireland; on the authority of Bailly

(1865c, p. 89) this is the probable locality of the holotype which is in the collections of Trinity College, Dublin; County Kildare, Ireland, British Museum Collection E 3,652; Waterford, County Wexford, Ireland, British Museum Collection E 361; Clitheroe, Lancashire, British Museum Collection E 4,353; Clitheroe, Lancashire, Sedgwick Museum, Cambridge, Collection 17; Hook Head, County Wexford, Ireland, Sedgwick Museum Collection nos. 1 and 5; Whatley, near Frome, Somerset, Strassburg Museum; East Burn, northeast of Stewarton, Scotland (Smith).

Taking up the specimens attributed to *Maccoya sphaerica*, a specimen in the British Museum Collection E 3,652, is from Kildare, and is free from matrix, but not very clearly preserved. It measures about 50 mm. in height and 52 mm. in diameter. The ambulacra are narrow, about 6 mm. in width at the mid-zone. The interambulacra are about 26 mm. in width. The ambulacral areas are rounded outwardly as in the type, but details of plates are obscure. Pore-pairs are alternate and plates are apparently alternately primary and occluded. In the only good interambulacral area there are seven columns of plates at the mid-zone. This specimen in structural detail resembles M'Coy's type more closely than any other specimen I have seen. It also resembles it very closely lithologically, which lends weight to Baily's statement that the type is probably from Kildare, which is the source of this individual.

In the British Museum Collection E 361, is a limestone slab from Waterford, Ireland, which bears two specimens, one of which is one of the finest of known Palaeozoic Echini. The slab measures 200 mm. long by 125 mm. in width. The more nearly perfect specimen is shown in Plate 32, fig. 4, and Plate 34, figs. 4-6. The test is spheroidal, somewhat crushed laterally. The ambulacra at the mid-zone measure about 7 mm., the interambulacra 25 mm. in width. From these measurements the circumference would be about 160 mm. and the diameter about 50 mm. Ambulacral areas are narrow, with two columns of low plates in each area. All plates meet the middle of the area, and at the mid-zone most of the plates reach the interambulacra, but alternately they are widened and narrowed marginally, the narrowed plates being nearly or occasionally quite excluded from contact with the interambulacrum. A few completely occluded plates occur in each of these specimens, though none is shown in Plate 34, fig. 4, the ambulacra in which are drawn somewhat diagrammatically with certain oversights. It was this specimen on which Professor Duncan (1889, p. 200, text-figs. ii-vii) based his observations of the structure of the ambulacrum in this species. In his text-figs. vi, vii, small demi-plates are shown which he letters as *a*. These plates, having been overlooked, are not shown in my figures, but nine such plates were counted in the best specimen (Plate 32, fig. 4). Such plates are not a character of this species or genus, and are to be considered as exceptional progressive variants. At the mid-zone the pore-pairs are biserial, the outer pore of one plate being about in line with the inner pore of the next succeeding plate. Dorsally, near the oculars, as a localized stage, all plates are of equal height, meet the interambulacra fully, and

pore-pairs are uniserial. The structure of the ambulacrum at the mid-zone is intermediate between that of *Palaeochinus* and *Maccoya*, and the alternate plates are not usually so completely cut off from the interambulacrum as was observed in M'Coy's type specimen. The interambulacra are wide (Plate 34, fig. 4), with five columns of plates in each area. In the second specimen, on the same slab, there are five columns in one interambulacral area and six columns in two other areas. The plates are hexagonal, or pentagonal in the adradial columns. The hexagons are much wider than high, one at the mid-zone measuring 7 mm. in width and 5.5 mm. in height. The ventral area is unknown. Ambulacral and interambulacral plates bear numerous small secondary tubercles, and in the second specimen there are in place small, tapering spines, swollen at the base, and about 3 mm. in length. All five oculars are in place. They are all insert, cover the ambulaera and laterally the interambulacra in part on either side. The genitals are wide, apparently very low for this family, but the ventral borders seem to be pushed under the interambulacra in part, which accounts for the height, and I think also for the absence of visible genital pores. The periproct is exceptionally perfect, the most nearly complete one known in the family. It differs slightly in Plate 34, figs. 4 and 6, but the latter I drew with all care, and it is to be considered a corrected drawing. The plates are numerous, small, angular, rounded up, so that they are higher in the center of each plate than on its sutural margin. They are strikingly close to the character of the same plates in the Recent *Cidaridae*, and may well stand as representing the typical Palaeozoic periproct, as this is the clearest and most nearly complete specimen in regard to this structure known to me from these ancient formations. This British Museum specimen E 361, is the one from which Duncan (1889, p. 196) described the apical disc with oculars reaching the periproct and with periproctal plates in place. Duncan's second specimen which he says is the same species, and describes as having the oculars excluded from the periproct, may have been the specimen in the British Museum (which was labeled *P. sphaericus*) which I refer to *Lovenechinus lacazei* (p. 328; Plate 36, fig. 6).

A specimen in the British Museum Collection E 4,353, from Clitheroe, Lancashire, is fragmentary. The interambulacral plates are very large, 11 mm. wide by 8 mm. high, representing a very large individual. Ambulacral plates are preserved only in fragmentary clusters of connected plates, but they are typically alternately primary and nearly, or in some plates quite, occluded, with pore-pairs biserial.

The Strassburg specimen of *M. sphaerica* from Whatley, consists of ambulacral and more or less dissociated interambulacral plates on a limestone slab. All the ambulacral plates meet the middle of the area, and also the interambulacrum, but alternate plates are enlarged or narrowed marginally (Plate 34, fig. 8), the latter not being quite cut off from interambulacral contact, in this respect being like the British Museum specimen E 361. The pore-pairs are biserial. As seen from within (Plate 34, fig. 9), all ambulacral plates are alike, of equal height, and pore-pairs are uniserial. This is the same relation as is shown between the inner and

outer aspect of ambulacral plates in *Maccoya intermedia* (Plate 33, figs. 7-9). The larger hexagonal interambulacral plates measure 7 to 7.4 mm. in width, and 5.8 to 6 mm. in height, so that they are distinctly wider than high. They have numerous secondary tubercles like those of Plate 32, fig. 4.

Of the specimens in the Sedgwick Museum, Cambridge, England, that from Clitheroe, no. 17, from the Aitkin Collection, consists of portions of ambulacra and dissociated interambulacral plates. Of the ambulacrals, all plates cross the half-areas, but alternate plates are partially pinched off marginally, and pore-pairs are biserial, as in Plate 34, fig. 8. Another specimen, from Hook Head, Ireland, no. 1, is the original specimen referred to by Keeping (1876, p. 38). What he described as an ocular plate with two pores, lies above an interambulacrum, though it is not in place. In my opinion it is not an ocular, but a genital, high, as usual, and with three pores, not two. There are some ambulacral plates in place and five columns of interambulacral plates, consisting of one column of pentagonal adradial, and four columns of rather low hexagonal plates. One or more columns are evidently wanting. A third specimen from Hook Head, no. 5, from the Walton Collection, consists of a portion of an interambulacrum, with four columns of plates in place, one column of pentagonal adradial and three columns of low hexagonal plates, which measure about 7.5 mm. in width by 5 mm. in height.

* *Maccoya gigas* (M'Coy).

Plate 46, figs. 1-3; Plate 47, figs. 1, 2.

Palacchinus gigas M'Coy, 1844, p. 172, Plate 24, figs. 4a-4c; Dujardin and Hupé, 1862, p. 463; Baily, 1874, p. 41, Plate 3, figs. a-d; Quenstedt, 1875, p. 380, Plate 75, fig. 40; Keeping, 1876, p. 38, Plate 3, figs. 12, 13; Julien, 1896, p. 130; (pars) Klem, 1904, p. 32.

MacCoya gigas Pomel, 1869, p. xlvi.

Palacchinus gigas Lovén, 1874, p. 41 (non Duncan, 1889, p. 198, text-fig. i; non Jackson, 1896, p. 204, Plate 7, figs. 38, 39¹).

Maccoya gigas Pomel, 1883, p. 115; Lambert and Thiéry, 1900, p. 119.

Non *Palechinus gigas* Tornquist, 1897, p. 739, which is based on Duncan's *Palacchinus gigas*.¹

The cotypes of this species which are in the Science and Arts Museum, Dublin, are the basis of M'Coy's and Baily's observations and also of my diagnosis. The whole test is unknown, but the parts which are known indicate that it was high, spheroidal. M'Coy's restored figure is, I think, much too low. Ambulacra are relatively narrow, about 10 mm. in width, and as shown by Baily, are composed of two columns of low plates, all of which meet the middle of the area, but marginally alternate plates are primaries, reaching the interambulacra and enlarged at

¹ Duncan's and Jackson's observations were apparently both based on the specimen in the Museum of Practical Geology which has a different ambulacral structure from *Maccoya*, and is here referred to *Lovenechinus anglicus* sp. nov. (pp. 304, 346, Plate 46, figs. 5-6; Plate 47, figs. 3-5).

that point, the plates between being narrowed marginally, ocluded, and cut out from interambulacral contact by the enlargement of their fellows; pore-pairs biserial (Plate 47, fig. 2). This is the typical generic character. On the interior of the test all ambulacral plates are of about equal height and cross the half-area completely, as shown in a specimen from Rahan's Bay, in the Sedgwick Museum, Cambridge, England, no. 3, which also shows that the ambulacral plates bevel over the adambulacra on the marginal suture, a structure similar to that shown in *Maccoya intermedia* (Plate 34, figs. 2, 3).

The interambulaera of the type (Plate 46, figs. 1, 2) are more nearly complete than those of any other known specimen of the species. This specimen is bent sharply on itself, as on a hinge, so that on one side (Plate 46, fig. 1) is seen an ambulacrum and three adjacent interambulacral columns, and on the reverse side (Plate 46, fig. 2) is seen an adradial pentagonal column and an adjacent column of hexagonal interambulacral plates. This structure is shown clearly in Baily's (1874, Plate 3, figs. a, b) excellent figures. M'Coy in his restoration assumed six columns in an area, which is very likely correct, but there may have been fewer, or possibly more than that number. The plates are very large and relatively high in proportion to their width. The pentagonal adambulacral plates measure about 12 mm. in width by 9 mm. in height; the hexagonal plates measure about 14 mm. in width by 9 mm. in height. These plates bear numerous secondary tubercles, as shown better in M'Coy's second type (Plate 46, fig. 3). The characters of the ventral and apical areas are unknown. This species is the type of the genus.

Arenaceous shale, Lower Carboniferous, Rahan's Bay, Dunkineely, County Donegal, Ireland, eotypes, two specimens, in the Griffith Collection, Science and Arts Museum, Dublin; same locality, Sedgwick Museum, Cambridge, England, Collection 3 and 266; Lower Carboniferous shale, Drumlug, County Donegal, Ireland, Trinity College Museum, Dublin; Régný, Central France (Julien).

The specimen from Drumlug in the Trinity College Museum shows an ambulacrum very clearly, in which all plates meet the middle of the area, but alternate plates are primary and ocluded, meeting or being cut off from the interambulacrum; pore-pairs are biserial, as in M'Coy's type. There is a column of large pentagonal adradial plates in place with the ambulacrum and in addition scattered interambulacral plates. One large adradial plate measures 16 mm. in width and 10 mm. in height.

The specimen in the Sedgwick Museum Collection no. 3, is an interesting individual of this species from Rahan's Bay, the type locality. This is the original of Keeping's (1876) Plate 3, fig. 13, as stated on the old and somewhat faded label. His figure, however, is somewhat inadequate. The specimen is a slab on which there are portions of an ambulacrum and ten more or less perfect and dissociated interambulacral plates. The ambulacral plates are in three short, but continuous pieces. All plates meet the middle of the area, but alternate plates

meet and are cut off from interambulacral contact (Plate 47, fig. 1); pore-pairs are biserial, as in M'Coy's type. The ambulacral plates bevel strongly over the adradials laterally. Adradial plates on the inclined marginal face show one set of facets distally for articulation with the primary ambulacral plates, but, passing proximally on the inclined face, these facets become narrower and other facets appear between them, so that proximally there are facets for each ambulacral plate of the area, as explained in detail in the case of *Maccoya intermedia* (p. 315, Plate 34, figs. 2, 3). The adradial plates of this specimen measure 8 mm. in width and the same in height, hexagonal plates 10 mm. in width and 8 mm. in height. Another specimen from Rahan's Bay, in the Sedgwick Museum, no. 266, consists of two large hexagonal interambulacral plates with good tubercles. The larger of these plates measures 12 mm. in width, 9 mm. in height. The size and locality indicate that it belongs to this species.

**Maccoya gracilis* (Meek and Worthen).

Plate 34, figs. 11, 12; Plate 35, figs. 1-3.

Palaechinus gracilis Meek and Worthen, 1869, p. 82; 1873, p. 473, Plate 10, fig. 2; Keyes, 1895, p. 180.

Palaechinus gracilis Lovén, 1874, p. 41; Duncan, 1889, p. 205.

Maccoya gracilis Pomel, 1883, p. 115; Lambert and Thiéry, 1910, p. 120.

Rhocchinus gracilis Jackson, 1896, p. 201, Plate 7, figs. 36, 37; Tornquist, 1897, p. 762; Klem, 1904, p. 29.

The test is small, high, spheroidal. In the holotype (Plate 35, fig. 1), the width of the ambulacrum at the mid-zone is 5.5 mm.; width of the interambulacrum about 19.5 mm. From these measurements the circumference would be about 130 mm. and the diameter about 41 mm. The ambulacra are narrow, composed of two columns of plates, all of which meet the middle of the area, but on the margin alternate plates are primaries, meeting and enlarged at the interambulacral contact; the plates between are occluded, marginally narrowed and nearly or quite cut off from interambulacral contact by the enlargement of their fellows. Pore-pairs biserial, the outer pore of the inner pair about in line with the inner pore of the outer pair.

Interambulacra are wide, in the holotype (Plate 34, fig. 11) with seven columns of plates at the mid-zone in the only area that is at all complete in this specimen. The adambulacral plates are pentagonal and those of intermediate columns hexagonal. Dorsally, the seventh column is interrupted, there being one row of six plates built, above which the seventh column appears again, with a pentagonal plate having a heptagon lying on its left lower border. Ambulacral and interambulacral plates alike bear small secondary tubercles.

Another specimen from Burlington in the Museum of Comparative Zoölogy (3,009) is a larger individual, but fragmentary and represented by an internal impression. There are six columns of interambulacral plates at the mid-zone. This specimen was incorrectly referred to *burlingtonensis* by me (Jackson, 1896, p. 204), as I was misled by the original label which bore that name.

In the Kentucky specimen referred to this species (Plate 34, fig. 12) there are seven columns of interambulacral plates at the mid-zone in each area, but an eighth column originates dorsally in each area, and in area C a ninth column is represented by a few plates near the apical disc. The ventral portion is unknown in the species and the dorsal portion is unknown in the type, but in this specimen, which is an external sandstone mold, impressions of insert oculars and wide, high genitals are visible dorsally (Plate 35, fig. 3).

Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa, holotype, from the Waehsmuth Collection 407, in the Museum of Comparative Zoölogy Collection 3,052; Lower Burlington Limestone, same locality and Museum 3,009; Waverly Group, Lower Carboniferous, Menifee County, Kentucky, two specimens on one slab, Museum of Comparative Zoölogy Collection 3,062.

The specimens from Menifee County, Kentucky (Plate 34, fig. 12; Plate 35, figs. 2, 3) are the only ones of this species known excepting those from Burlington as described above. The better of the two is figured. The specimen is an external sandstone mold of the dorsal side, therefore in the figures the orientation is reversed from what it would be if viewed from the exterior. The ambulacra are narrow, 5 mm. in width at the widest part, which is narrower than in the type, but the specimen is smaller, and the interambulaera at the widest part are 14 mm. across. Details of ambulacral plates cannot be ascertained, and as restored by dotted lines in Plate 34, fig. 12, are doubtless given incorrectly, but this figure was drawn in 1895 when I had not studied the type. Interambulaerum A (Plate 34, fig. 12) is the most nearly complete area; ventrally there are five columns of plates, above which the sixth and seventh columns are introduced with pentagonal plates; farther dorsally, an eighth column comes in at the left of the center with a heptagonal plate on its right ventral border (just the reverse as seen from the exterior). In the several other areas there are seven columns of plates in the most adoral portion preserved, and farther dorsally in each area, an eighth column is introduced with a pentagonal plate. In area C the eighth column appears somewhat earlier than in the other areas, and near the apical disc a ninth column is represented by three small plates. This specimen occurs in the Waverly Group, which is somewhat older than the Burlington Limestone, but I think the specimen is referable to *M. gracilis*. The only differences seen are the somewhat narrower ambulacra and the eighth column of interambulacral plates dorsally. The type might have shown this additional column if it were complete to the apical disc.

LOVENECHINUS gen. nov.

Test spheroidal, ambulacra relatively narrow, with four columns of plates at the mid-zone, which consist of two columns of narrow demi-plates and two columns of wider oeccluded plates, without intercalated isolated plates. The wide oeccluded plates are roundly arched upward in the center, and this is the beginning of that dominating prominence of the two

occluded columns, which is a marked feature of the next genus, *Oligoporus*, and especially most species of *Melonechinus*. The pore-pairs are biserial in sunken valleys on either side of the ambulacral areas, and the pores are situated in that portion of each plate nearest the next adjacent interambulacrum. All this as seen from the exterior; on the interior (Plate 43, figs. 4, 5) demi- and occluded plates are of about equal width, and pore-pairs lie near the middle line of each half-area, also demi-plates which lie opposite horizontal interambulacral sutures are higher and fan-shaped. Ventrally, next the peristome (Plate 42, fig. 1), ambulacral plates built in youth are all primaries, with pore-pairs uniserial (as in adult *Palaeochinus*). Above this zone plates are primary and occluded, with pore-pairs biserial (as in adult *Maccoya*), before attaining the character plates of the genus. Dorsally, a comparable condition occurs next the ocular in the placogenous zone (Plate 42, fig. 3); here ambulacral plates are primaries with pore-pairs uniserial. Passing ventrally, the older plates are alternately primary and occluded as localized stages in development, before they acquire the full characters of the genus. Ambulacral plates bevel over the adradials laterally, and bear small secondary tubercles and spines only.

The interambulacra are wide, with from four to seven columns of plates in an area at the mid-zone in the known species, composed of pentagonal adradial, and hexagonal median plates. There are ventrally two plates in the basicoronal row, above which additional columns come in as usual in the family (Plate 45, fig. 1). There is no imbrication in ambulacral or interambulacral plates, but the adradials bevel under the ambulacrals laterally. Interambulacral and ambulacral plates bear secondary tubercles and spines only. Peristome and jaws are unknown; but they were doubtless similar to those of *Oligoporus* and *Melonechinus*.

Oculars are usually all insert but one or more may be exsert. They are imperforate as seen from the exterior, but indications of a pore on the interior have been seen in some cases (Plate 41, fig. 2; Plate 42, fig. 6). Genitals are high, wide, with from three to five genital pores each; a madreporite has apparently been observed in one specimen (p. 334; text-fig. 243, p. 331). Small angular periproctal plates, as usual in the family, have been seen in one specimen (Plate 42, fig. 6).

The type species is *Lovenechinus missouriensis* (Jackson). This genus differs from *Maccoya* in that ambulacral plates are demi- and occluded instead of primary and nearly or quite occluded. It differs from *Oligoporus* in that there are no scattered isolated plates in the middle line of each half-area as in that genus, also as a correlated character in that pore-pairs are biserial instead of multiserial. *Lovenechinus* in its development passes through a stage like the adult of *Maccoya*, and *Oligoporus* in its development passes through a stage like the adult of *Lovenechinus* (text-fig. 237, p. 231). It is thus a type structurally and phylogenetically intermediate between *Maccoya* and *Oligoporus*. *Lovenechinus* includes certain species previously referred to either *Palaeochinus* or *Oligoporus*, with two new ones (p. 304).

² These references are all in regard to the specimen from Helsington Barrows in the Jermyn St. Museum, described by Dunean (1889, p. 200, text-fig. viii) as *Palaeochinus ellipticus*; but here referred to *Lovenechinus lacazei* (footnote p. 303, p. 328, Plate 36, figs. 1-3). The *Palaeochinus ellipticus* M'Coy (1844, p. 172, Plate 24, figs. 3a-3d) is an entirely distinct species and is here considered on p. 307, Plate 29, fig. 2, Plate 30, figs. 8-10.

This species includes specimens of various sizes and many localities, but as the structure in all is essentially the same, as far as known, I consider them a single species. The specimens from Llysfaen (Plate 35, fig. 6; Plate 36, figs. 7, 8) and from Kirkby Stephen (Plate 35, fig. 7; text-figs. 240-243, p. 331) are much larger than the other known specimens. It is possible that these two may prove to be a closely related but distinct species. As they show no structural differences, however, I consider them the same as the smaller specimens.

Test spheroidal, or in one case moderately elliptical. Ambulacra narrow, composed in each area of four columns of plates, which are narrow demi- and wider ocluded plates in each half-area, pore-pairs in that portion of each plate nearest the next adjacent interambulacrum. Ambulacral plates low, covered with minute tubercles. From six to eight (or in the Kirkby Stephen specimen five and a half) demi-plates equal the height of an adradial. Ventrally ambulacral plates are primaries with pore-pairs uniserial (Plate 36, fig. 2; Plate 38, fig. 2).

The interambulacra in all known specimens have four columns of plates in an area at the mid-zone, the adradials being pentagonal, the median hexagonal. These plates bear minute tubercles and corresponding spines, the latter known only in the Kirkby Stephen specimen. The oculars as far as known (Plate 36, fig. 6; text-fig. 243) are small and fully exsert, an exceptional Palaeozoic character (p. 89). Genitals are wide, high, with from two to four genital pores each (Plate 36, figs. 4, 6, 7; text-fig. 243). This last figure apparently shows a madreporite as observed by Dr. Bather. Periproctal plates are not known.

Lower Carboniferous, l'Ardoisière, Central France, cotypes in the possession of the family of the late Professor Julien; Hunsrück, Germany (Tornquist); Hook Head, County Wexford, Ireland, Science and Arts Museum Collection, Dublin; Helsington Barrows, southwest of Kendal, Westmoreland, Museum of Practical Geology Collection 16,301; Armagh, Ireland, two specimens, British Museum Collection E 10,051, and E 10,052; Llysfaen, near Llandulas, Wales, British Museum Collection E 3,432; Kirkby Stephen, Westmoreland, England, Yorkshire Philosophical Society Museum Collection; Marbre Noir de Dinant, Belgium (Fraipont).

I will consider now the several recorded specimens, with the principal features of each. Professor Julien's types from l'Ardoisière, as gathered from his figures and description, have four columns of ambulacral plates in an area, wide ocluded and narrow demi-plates, which latter alone reach the interambulacra. Two pores are in each plate, situated near the marginal suture. Ambulacral plates are low, six equaling the height of an adambulacral plate. Interambulacra with four columns of plates in an area, the plates being pentagonal in adradial columns, and hexagonal in the median columns. According to Julien, the adradial plates measure 6 mm. in width by 5 mm. in height, the hexagonal 7 mm. in width by 5 mm. in height. They do not show any imbrication. Ambulacral and interambulacral plates alike with numerous small granulations, which Julien says do not merit to be called tubercles, but I do not see that

they are at all different from the small secondary or, possibly better, miliary tubercles in other species of this family. The dorsal portion is not figured or described by Julien.

Tornquist next took up this species and published a detailed description of his specimens, with excellent figures, including a good restoration of the whole test. He shows (my Plate 38, figs. 1-3) that there are four columns of ambulacral plates as the species character, wide occluded and narrower demi-plates, with pore-pairs in peripodia, biserial, situated near the interambulacrum on the exterior, but near the middle of the half-area on the interior of the test. He shows that ventrally ambulacral plates are primaries, of equal width, with pore-pairs uniserial. There are four columns of interambulacral plates in an area, and both these and the ambulacrals bear small secondary tubercles.

In the British Museum there are two specimens clearly referable to this species, from Armagh, Ireland, numbers E 10,052 and E 10,053. In the larger of these (Plate 35, fig. 5; Plate 36, figs. 4, 5) the ambulacrum at the mid-zone measures 7 mm. in width, the interambulacrum 16.5 mm. From these measurements the circumference would be about 117.5 mm. and the diameter about 37 mm. The height is about equal to the diameter. The ambulacra are narrow and at the mid-zone have four columns of narrow demi- and wide occluded plates, the pore-pairs are biserial, lying near the next adjacent interambulacrum. Interambulacra are wide, with four columns of plates in two areas, seen dorsally only in area A. The plates are pentagonal adradials and hexagonal in the median columns. A hexagon at the mid-zone measures 5 mm. in width by 4.2 mm. in height. Dorsally, in area A, a genital plate in place is high, wide, with three genital pores. The second specimen from Armagh (Plate 35, fig. 4; Plate 36, fig. 6) presents the dorsal portion only. The ambulacrum is similar to the last, and there are four columns of plates in three interambulacral areas. The most important feature is the apical disc, unknown in the type specimen. There are three oculars in place which are small and triangular in form, and all are fully exsert. Oculars D and F are as fully excluded as is ocular B (the drawing being not quite correct in this point, as I have recently ascertained by examining the specimen). The oculars cover the ambulacra and in area E the interambulacra in part on either side as usual. They do not impinge on the interambulacra in areas A, G, and in the left side of C, but this lack is ascribed to local disturbance in fossilization, as I have found so universally that oculars do reach the interambulacra in Echini (p. 86). The genitals are high and wide, and three have three pores each, but one has only two pores. This specimen was labeled "*Palaeochinus sphaericus*" and it is probably the one referred to by Duncan (1889, p. 196) as *Palaeochinus sphaericus* of which he says that the oculars are all excluded from the periproct (p. 320).

A specimen from Helsington Barrows, in the Museum of Practical Geology Collection 16,301, is ascribed to this species (Plate 36, figs. 1-3). The ambulacra are narrow, with four columns of demi- and occluded plates at the mid-zone, and pore-pairs are biserial. Ventrally, near the

peristomal border, the plates are primaries only, with pore-pairs uniserial, a typical character of this zone in the genus. The interambulaera are somewhat imperfect and a number of plates are restored in area A as indicated by dotted lines. With this restoration (a space for which exists in the specimen), there are four columns of plates in the area. Both ambulacral and interambulacral plates in part bear small secondary tubercles. This specimen is of importance, as the one from which Dunean (1889, p. 200, text-fig. viii) described the structure of the ambulacrum as that of *Palaeochinus ellipticus*. He was perhaps misled by the original label, which reads *Palaeochinus ellipticus* M'Coy, but since studying M'Coy's type of *ellipticus* in Dublin, I know that this was a mistake of identification. The structure of the ambulacrum and the interambulacrum in this specimen differs essentially from that of *P. ellipticus* (Plate 29, fig. 2; Plate 30, figs. 8-10; p. 308, and footnotes, pp. 303, 326).

A specimen from Hook Head, Ireland, in the Science and Arts Museum, Dublin, has the same structure as that last described, with four columns of demi- and occluded ambulacral, and four columns of interambulacral plates. The size is about the same as that of the Hel-sington Barrows specimen.

The specimen from Llysfaen in the British Museum Collection E 3,432 (Plate 35, fig. 6; Plate 36, figs. 7, 8) I ascribe to this species with much hesitation, as it differs so much in size and superficial appearance from those previously described. However, as it has the same structural character as typical *lacazei*, it is placed in this species. The test is large, rounded, and somewhat elliptical, but its actual height is apparently greater from the dorsal dislocation of plates. It is a superb specimen, finely preserved. Width of ambulacrum at the mid-zone, 10 mm., interambulacrum, 30 mm. From these measurements the circumference would be about 200 mm. and diameter about 64 mm. The height as estimated is about 72 mm. and the width, if completed on the left side, about 68 mm. The ambulacra at the mid-zone have four columns of plates which are narrow demi- and wide occluded. Pore-pairs lie near the next adjacent interambulacra. About eight demi-plates at the mid-zone equal the height of an adradial. The ambulacra are high, rounded, and laterally bevel over the ambulacrals on the adradial suture. In ambulacrum B ventrally, as shown in the specimen (not in the drawing), within about 10 mm. of the base, the ambulacral plates are all primaries crossing the half-areas, and pore-pairs are uniserial, as in the ventral area of other species of the genus. There are four columns of plates in an interambulacral area at the mid-zone and throughout most of the vertical extent of the area, as shown in area A. The same is true of area I, and a third area on the reverse side. In area I ventrally (not shown in the drawing), there is a single plate representing the left of the two plates of the basicoronal row, three plates in the second row, and four plates in the third row, as in text-fig. 25, p. 70. The surface of the plates is high, rounded, and covered with small secondary tubercles. A single genital plate dorsally in place is high, wide, with three genital pores. Three other genitals are more or less displaced, and

with pores showing in part only. A small triangular ocular lies next to genital A and is similar in size and appearance to the small oculars shown in text-fig. 243.

The specimen from Kirkby Stephen and now in the York Museum, is the original described by de Koninck (1869, 1870) as *Palaechinus sphaericus*. De Koninck's description and figures have entered much into succeeding publications (footnotes, pp. 303, 317, 326). In considering these, I found discrepancies and characters which I could not account for, and at my request my friend Dr. F. A. Bather, most generously came to my aid, borrowed the specimen, developed it with great pains, and sent me the accompanying photographic figure and drawings (Plate 35, fig. 7; text-figs. 240-243). I would express to him my heartiest thanks for this most friendly and important service. As seen by the figures, the specimen is not a *Maccoya sphaerica* (M'Coy), and does not belong to that genus, the ambulacra being quite different from those of *sphaerica* (Plate 34, figs. 4-10) and from M'Coy's description (p. 318). Further, oculars are present, not absent, as claimed by de Koninck, a very important point, for now one can say that they are not absent in any known regular echinoid. The following description is taken from Dr. Bather's critical and painstaking notes. This specimen in character is close to the British Museum specimen from Llysfaen, and it is possible that they may form a species distinct from *lacazei*, but as they agree with it structurally, they are included here.

Dr. Bather writes, "The specimen was originally in the collection of Mr. Edward Wood, F. G. S., of Richmond, Yorkshire, and came as part of the Reed Collection to the Museum of the Yorkshire Philosophical Society. Thence it was kindly lent to me by Mr. Oxley Grabham. It was at once obvious that de Koninck's sketch was not merely diagrammatic, but inaccurate in several important particulars. It was not, however, clear that his statement as to the oculars was incorrect. Indeed, it took me several weeks of careful preparation before all the questions asked me by Dr. Jackson could be answered with the aid of a good lens under the most favourable conditions of illumination. The wisest course, therefore, seems to be to draw up a fresh description of this interesting specimen.

"The echinoid lies at the corner of a fragment of pinkish grey limestone, weathering to a darker red of almost haematite tinge. This deep color is now, however, destroyed by the methods of preparation. The matrix can never, I think, have borne to the fossil quite the relations shown in de Koninck's figure. In that figure the upwardly directed ambulacrum is the anterior one, and the left-hand boundary of the matrix now passes upwards in continuation of its median line. From the angle where the matrix joins this ambulacrum to the limit of the posterior interradius, the length of the exposed test is 60.7 mm. The distance from the same point to the apical pole is 44 mm. The distance from the apical pole to the visible end of the right anterior ambulacrum is about 36 mm., and to the visible end of the adjacent right posterior interradius about 26 mm. It may be inferred from these measurements that the diameter of the test was about 55 mm., and that its height was rather greater.

"In the corona the general relations of the interambulacra and ambulacra are remarkably clear owing to the depression of the adradial sutures, from which the interambulacra rise up in a flattened curve, and the ambulacra in a more prominent sharply rounded curve.

TEXT-FIGS. 240-243.—*Lovenechinus lacazei* (Julien). Lower Carboniferous Limestone, Kirkby Stephen, Westmoreland, England; Yorkshire Philosophical Society Museum Collection. Drawn by A. H. Searle under the direction of F. A. Bather.

240. View of whole specimen, oriented by the madreporic pores in genital 2. $\times 1.5$. Four columns of plates in each ambulacral area, pore-pairs biserial. Four columns of plates in each interambulacral area. Same specimen as photographic figure, Plate 35, fig. 7.

241. Ambulacrum III enlarged $\times$ about 4. Plates X, and XX, correspond with the similarly marked plates in text-fig. 240.

242. Ambulacral detail much enlarged.

243. Dorsal aspect enlarged $\times$ about 3.8, showing small triangular exsert oculars; genitals high, wide, with three genital pores each, excepting genital 3, which has four pores; fine madreporic pores in genital 2, a very rare character to be seen in this family (p. 172). (The lettering of the figures is mine.)

"The ambulacra are composed of four columns of plates. The inner rows meet in a zigzag radial suture. The outer end of each plate, bearing a pore-pair, interlocks with the inner ends of the two adjacent outer plates. The outer plates then expand and bear pore-pairs alternating with those of the inner series. This structure obtains in all visible parts of the ambulacra, from the apical end to the ambitus. The number of ambulacrals corresponding with an interambulacral is 10 to 12, and this relation also appears fairly constant, the ambulacrals being reduced in height in proportion to the height of the interambulacrals. The fifth interambulacral from the summit, in the left anterior interambulacrum, has a height of 4.5 mm. and a greatest width of 4.7 mm. The total width of the anterior ambulacrum at the adoral margin of this plate is 6.2 mm.; about five and a half ambulacrals of the outer series abut against it, so that the height of each ambulacral here is about 0.8 mm.

"The whole of the poriferous tract of each ambulacrum is depressed, and from it the perradial tract of the ambulacrum rises in a well marked curve. The perradial tract bears miliaries like those of the interambulacrals, from 6 to 8 being on the adradial portion of each ambulacral plate of the inner series, and a single miliary on the adradial tongue of each ambulacral of the outer series. These miliaries are regularly arranged in diagonal rows, crossing at a constant angle. I am unable to detect on these miliaries any definite mamelon or any perforation, or any suggestion of a scrobicule surrounded by a scribiocular ring. That is why I call them miliaries and not tubercles. W. H. Baily has described and figured very precisely all those appearances in the corresponding structures of *Palaeochinus elegans* (Journ. Roy. Geol. Soc. Ireland, vol. 1, p. 63) and *P. gigas* (*op. cit.*, vol. 4, p. 41), and I should be glad to know whether anyone has ever confirmed his observations. [I have not seen such a structure in any species in this family.—R. T. J.]

"The pore-pairs are surrounded by a rim [peripodium], and the interporal septum is well defined and prominent. These structures, however, have been considerably worn in the preparation of the specimen. The pores are not circular. Those of the inner pair are together like the outline of a hen's egg, cut across at the septum, the broader half of the egg being adradial. In the outer pore-pair, the adradial pore is of similar shape, but the outer pore lies close to the margin of the ambulacrum and appears as though compressed thereby into an ellipse with its long axis parallel to the margin.

"The adradial suture. Owing to the position of the outer pore-pairs and to the sudden uprise of the adjacent interambulacrals, the ambulacrum, when viewed superficially, seems to dip under the interambulacrum, as in the flexible suture of primitive Cidaridae. The suture was probably not flexible; the abutting plates are very thick, about 3.5 mm. near the ambitus; and the suture-face of the interambulacrum dips towards the perradius [that is, ambulacrals bevel over the adradials, a typical character in this family.—R. T. J.]. The pore-canals of the ambulacra also slant in the same direction. These facts, seen somewhat obscurely at the

broken ends of the two ambulacra on the left, are more than confirmed by a larger specimen of this species in the British Museum (E 3,432) from the Carboniferous Limestone of Llysfaen, near Llandulas [my Plate 36, fig. 6]. This specimen further shows that the adradial suture face of the interambulacrum is denticulate at its outer margin, and faintly grooved over all its surface for the reception of the outer ambulacrals.

"The interambulacra are closely united to the genital plates by the proximal plates of their admedian columns. Immediately adjoining these plates the proximal plates of the outer columns make their appearance. The area in which most is preserved is the right anterior, which is visible at least as far as the ambitus and possibly further. Throughout the whole of this there is no evidence for more than four columns, although de Koninek's figure shows a fifth coming in. The plates of the outer columns are pentagonal, and about the ambitus attain a width of 7.4 mm. with a height of 5 mm. Those of the admedian columns are hexagonal and, at the same level, have a width of 6.4 mm. and a height of 5.1 mm. The total width of the interambulacrum here is about 22.5 mm.

"The interambulacrals are covered with miliaries, about four to the square millimeter, showing a slight tendency to be arranged in rows. They bore small radioles of which the remains are seen in the adradial furrows. The plates seem firmly united by vertical sutures.

"Remains of minute radioles, with fine longitudinal striation, are preserved in the matrix, especially in the grooves on each side of the ambulacra.

"The apical system consists of five genitals (or basals) and five oculars (or radials).

"The five oculars are minute triangular plates, squeezed like wedges between the genitals. They are depressed and bear miliaries like those of the genitals. Having with much trouble removed the matrix, I can now see the outlines of all, except the suture separating the anterior ocular from the left anterior genital. The plates are about 1.4 mm. high and about 0.8 mm. wide at the base, or adoral margin. On none can I detect any trace of an ocular pore, nor are the miliaries arranged round any depression where a pore might lie. Of course these pores are notoriously difficult to see in all fossil echinoids, so that it does not appear necessary to adopt the alternative view that the ocular tentacle may have emerged between the ocular and the ambulacrum. [I have not seen a pore on the exterior of an ocular plate in any species of this family.—R. T. J.] Each ocular lies below the level of the adjacent genitals and bends sharply down to meet the ambulacrum almost at right angles. This gives the impression that the ambulacrum passes beneath the ocular and that the union was flexible; but it is difficult to see clearly into the angle.

"The genital plates form a closed circle, with abutting sides about 1.2 mm. long. Four of the genitals are approximately equal in size and form, having a width of about 4 mm., measured from the distal ends of the interbasal sutures, and a height, measured along the interradius, not exceeding 3.5 mm. The outline of these plates is much more pentagonal than heptagonal;

for, though strictly speaking all have nine sides, some of these sides are very short and almost in a line with one other of those adjoining. The fifth genital (the madreporite) has a width of 3.6 mm. measured at the same level as the other genitals; but, whereas the other genitals scarcely, if at all, increase in width distally, this plate, owing to its greater height, *viz.*, 5.4 mm., attains ultimately a width of 5.7 mm. This plate also is pentagonal in general outline, though it abuts, not only on interambulacra as do the other genitals, but also on the adjacent ambulacra for about 1.5 mm. [I have found so generally in Palaeozoic and later Echini that ocular plates cover the ambulacra and laterally in part the interambulacra on either side (pp. 62, 86) that I think the lack of this latter character in the specimen here described may be due to displacements in fossilization — R. T. J.]

“Each genital plate, including the madreporite, is pierced by three rounded and well marked pores; but the left anterior has a fourth pore. In three of the four ordinary genitals, these pores follow a curved line, about 0.8 mm. from the adoral margins. In the right posterior genital the two pores next the anterior margin are close together, and one of them is distal to the other. The pores of the madreporite are placed quite differently, one being near the adapical margin, the other two at irregular distances from the adoral margins. It is probable that the normal position of the pores is presented by the two genitals furthest from the madreporite, and that the modifications in the two abutting on the madreporite were induced by the proximity of the stone-canal, which may have checked the symmetrical development of the gonads. [I have not found such irregularity in other cases in this family (Plate 42, fig. 6).— R. T. J.] The genitals are covered entirely but irregularly by miliaries, four or five to the square millimeter. These form circlelets round the gonopores. The madreporite also shows a multitude of punctae, much smaller than either the round pores or the miliaries. These may be the usual minute pores of the madreporite; but they may be due merely to a looser texture in this plate; that is to say, a larger proportion of stroma. On the latter interpretation the pore next the adapical margin, which is larger, more transversely elongate, and in more of a depression than the others, would have been the hydropore, and probably not a gonopore, as all the round pores doubtless were.

“The periproct is, in the fossil, a pentagonal opening, with a diameter of 4 mm., and almost equal sides formed by the genital plates. The side formed by the right anterior genital (the madreporite) is slightly shorter than the others.”

Of the specimens from Dinant, Belgium, which Fraipont refers to this species, all are moderate sized, with four columns of interambulacral plates in each area, as clearly shown by his excellent photographic figures, which are similar to my Plate 35, figs. 4, 5. He says that the details of the ambulacra could not be ascertained, but, as in every other respect the specimens are referable to this species, it seems that they may safely be considered as belonging to *L. lacazei*. The only other European species in the family which has a spheroidal test and four

columns of interambulacral plates is *Maccoya intermedia*, and so far this species has been recorded from Ireland only. The two larger specimens which Fraipont doubtfully refers to *lacazei* have each four columns of interambulacral plates, and are quite similar in appearance to the Kirkby Stephen specimen (Plate 35, fig. 7), so that I should equally refer them to *Lovenechinus lacazei*.

***Lovenechinus mutatus* (Keyes).**

Plate 38, figs. 10, 11.

Oligoporus mutatus Keyes, 1894, p. 126, Plate 15, figs. 4a, 4b; 1895, p. 183, Plate 18, figs. 4a, 4b; Klem, 1904, p. 39; Lambert and Thiéry, 1910, p. 121.

Test spheroidal, with strongly marked melon-like ribs. Ambulacra less than half the width of the interambulacra, composed of four columns of low plates at the mid-zone, two of narrow demi-, and two of wide ocluded plates. Pore-pairs in peripodia lying in that portion of each plate nearest the marginal portion. Ocluded plates elevated in a high, steep, median, rounded ridge. According to Keyes's figure, the ocluded plates do not enter between the demi-plates in a tongue-like fashion, as in *L. nobilis* (Plate 38, fig. 6), but the contact is rather serrate, as in *L. septies* (Plate 45, fig. 3) and *Oligoporus danae* (Plate 50, fig. 7). According to his figures also each demi-plate bears one small secondary tubercle and each ocluded plate bears three or four of the same in a nearly continuous horizontal row.

The interambulacra are wide, steeply rising from the adradial suture, then roundly curved across the area. There are five columns of plates in an area at the mid-zone, the adradial plates are pentagonal, the median hexagonal, their surfaces covered with small secondary tubercles.

This species is known only from Dr. Keyes's original description; the holotype is in the private collection of Mr. L. S. Cox of Keokuk, Iowa. It is smaller than, but structurally close to *L. nobilis*, from which it differs in the single row of tubercles on ambulacral plates, the shape of demi- and ocluded plates at their point of contact and the carinate edges on the sides of the interambulacra where they dip down to the adradial sutures.

Keokuk Limestone, Lower Carboniferous, Keokuk, Iowa (Keyes).

****Lovenechinus nobilis* (Meek and Worthen).**

Plate 37, figs. 1-3; Plate 38, figs. 4-9.

Oligoporus nobilis Meek and Worthen, 1868, p. 358; 1873, p. 476, Plate 11, fig. 3; Lovén, 1874, p. 42; Keyes, 1895, p. 182; Jackson, 1896, p. 198, Plate 6, fig. 35; Klem, 1904, p. 39; Lambert and Thiéry, 1910, p. 121.

Melonopsis nobilis Meek and Worthen, 1873, p. 478.

This fine species is spheroidal in form with elevated melon-like ribs. The plates are the most massive of any known Echini. Measurements of the type as given by Meek and Worthen

(1873) are: height and breadth about 3.73 inches each, width of the ambulacra about 0.6 of an inch, width of the interambulacra about 1.06 inches. The height of the largest interambulacral plates is 0.26 of an inch, width 0.40 of an inch, and thickness 0.25 of an inch. In a splendid specimen in the U. S. National Museum (Plate 37, fig. 3), the ambulacra at the mid-zone measure 17 mm. in width, interambulacra 40 mm. The height as estimated is something less than the width. Two specimens in the Museum of Comparative Zoölogy (Plate 37, figs. 1, 2) have about the same proportions, but one of these (fig. 2) is more massive, the interambulacrum measuring 50 mm. in width. The very thick plates are seen well in these two specimens. The plates in the middle of the ambulacrum and the interambulacrum (Plate 37, fig. 1) measure 7 mm. in thickness, but at the adradial suture they are only 3 mm. thick. The type according to Meek and Worthen is an internal siliceous mold, so that as this was a unique specimen the thickness of the plates was not shown.

The ambulacra are relatively broad, with four columns of plates at the mid-zone, two of narrow demi- and two of wide ocluded (Plate 38, figs. 5, 6). The demi-plates bevel strongly over the adradials, the ocluded medially rise into a high rounded ridge, in the center of which the plates attain a thickness of some 7 mm. The inner face of the test (Plate 38, fig. 9) presents no corresponding elevation, but rather is on one continuous curve of a practically uniform arc throughout. The ocluded plates laterally intercalate in a tongue-like end between the elongated and narrowed corresponding tongues on the inner ends of the demi-plates. The inner end of the tongue of the demi-plates in some cases is superficially almost or entirely separated from the body of its plate by the expanded tongues of the ocluded plates (Plate 38, fig. 6). Pore-pairs are situated in the outer tongues of the ocluded plates and close to the marginal suture in the demi-plates. Ocluded plates bear double alternating rows of small secondary tubercles, the outlines of the plates waving in correspondence with their position. The demi-plates bear usually only a single tubercle on the rounded inner end of the tongue. About five or five and a half demi-plates equal the height of an adradial.

The interambulacra are roundly curved and laterally dip down to the adradial sutures where they bevel under the ambulacrals (Plate 38, fig. 9). There are five columns of plates at the mid-zone in all areas of the specimens seen. The thickest plates are in the center of the area, and the thinnest are the pentagonal adradials. All five columns extend throughout the areas as far as observed; but the ventral developmental stages are not preserved in known specimens. The surface of the plates is covered with numerous small secondary tubercles, similar to those of the ambulacral areas.

According to Meek and Worthen, the apical disc in the type specimen is similar to that of *Melonechinus multiporus*, the ocular and genital plates being much the same. No pores were seen in the oculars, and the genitals, as far as ascertained, had four or five pores each. Two of the genitals have five pores each, one apparently five, and two apparently four pores each. The apical disc is not preserved in specimens I have seen.

The type specimen is from the Burlington Group, Lower Carboniferous, Calhoun County, Illinois. It is said to be in the Worthen Collection, now in the University of Illinois, at Urbana, Illinois; same locality and horizon, United States National Museum Collection 33,277; Webb City, Missouri, Museum of Comparative Zoölogy Collection 3,123 and 3,124; Keokuk Limestone, Keokuk, Iowa, a fragmentary specimen, American Museum of Natural History Collection 7,245; Boone Formation, Lower Carboniferous, western Arkansas, a specimen collected and loaned me by Dr. G. H. Girty.

The National Museum specimen of this species is a magnificent individual, one of the finest Palaeozoic Echini seen (Plate 37, fig. 3; Plate 38, figs. 6, 7). Besides having the typical species characters as described, this specimen shows dorsally a few ambulacral plates which are primaries crossing the half-area (Plate 38, fig. 7). This is the same feature of dorsal simplicity seen more completely in *L. missouriensis* (Plate 42, fig. 3).

In the Museum of Comparative Zoölogy specimen (Plate 37, fig. 1; Plate 38, figs. 8, 9), the test is spheroidal without compression. It shows the massive character of the plates, the lateral beveling of ambulacrals, and ventrally, as an internal mold in part, an impress of the proximal faces of plates. Another specimen in the same museum (Plate 37, fig. 2; Plate 38, figs. 4, 5) is less nearly complete, but represents a larger individual, the interambulacrum being about 50 mm. in width. It shows clearly surface characters, ambulacral detail, and the thickness of plates. Adambulacral plates are rounded in outline on the internal face of the adradial suture as in *missouriensis* (text-fig. 244).

****Lovenechinus missouriensis* (Jackson).**

Text-figs. 11, p. 54; 18, p. 59; 221, p. 193; 237, p. 231; 244, p. 338; Plate 39, figs. 1-6; Plate 40, figs. 1-3; Plate 41, figs. 1-3; Plate 42, figs. 1-7; Plate 43, figs. 1-5; Plate 44, figs. 1-5; Plate 46, fig. 4.

Oligoporus missouriensis Jackson, 1896, p. 184, Plate 9, figs. 50-52; 1899, p. 131; A. Agassiz, 1904, p. 80; Klem, 1904, p. 38; Fraipont, 1904, p. 11; Lambert and Thiéry, 1910, p. 121.

This species is represented by a fine series of specimens of various ages. It is largely known from internal or external siliceous molds, but in two examples seen the plates are preserved intact.

Test spheroidal, somewhat wider than high. The holotype (text-fig. 244) measures 90 mm. in height. It is somewhat flattened laterally, and measures through the mid-zone 96 mm. in greatest diameter, and 70 mm. in a plane at right angles to this but in the same zone. A very large specimen, but somewhat compressed (Plate 39, figs. 4, 5), measures about 86 mm. in height and 93 mm. in diameter through the plane J, E, also 90 to 99 mm. in other horizontal planes. If the plates were in place, it would measure several millimeters more. A smaller but quite uncompressed specimen (Plate 44, fig. 2) measures 59 mm. in height, 62 mm. in diame-

ter through the mid-zone. Another specimen with plates all in place (Plate 46, fig. 4), in Mr. F. Springer's collection, measures 91 mm. in height, and 91 mm. in diameter through the

mid-zone; the ambulacra at the mid-zone are a little more than 10 mm., and the interambulacra are about 44 mm. in width.

The original description was based on an internal mold, and as the external characters differ considerably from the internal, certain features given as specific need modification, and both internal and external aspects have to be taken into account (p. 60).

The ambulacra are relatively narrow, composed of four columns of plates at the mid-zone. As seen from the exterior, the demi-plates are narrow, the ocluded wide, with pore-pairs in that portion of each plate nearest the next adjacent interambulacrum (Plate 42, figs. 2, 3; Plate 43, fig. 3). The ocluded plates are arched up in an elevated median ridge which is formed wholly by the thickening of plates, no corresponding arch existing beneath them. The ocluded plates

TEXT-FIG. 244.—*Lovenechinus missouriensis* (Jackson). Burlington Group, Lower Carboniferous, Webb City, Missouri, Museum of Comparative Zoölogy Coll., 3,078 (from R. T. J. Coll.), holotype. Natural size. Four columns of ambulacral plates, demi- and ocluded, of about equal width. Demi-plates opposite horizontal interambulacral sutures fan-shaped, pore-pairs in middle of half-areas. In area A a sixth column is represented by three plates 6, 6' and the next succeeding aboral plate. Adambulacral plates rounded on the adradial suture. The smaller figure (a) shows an enlargement, $\times 2$, of ambulacral detail.

are produced as tongues laterally, which fit between corresponding tongues extending inward of the adjacent demi-plates. Ocluded plates bear two rows of alternating small secondary tubercles, the margins of the plates curving to correspond to the positions of the same. A single tubercle exists on the inner tongue of the demi-plates. While this is the character of plates at the mid-zone and throughout the greater part of the test, ventrally the plates built in youth, and young plates dorsally near the apical disc are primaries, or otherwise simple (Plate 42, figs. 1, 3), as later described in detail. Four or five demi-plates equal the height of an adradial, and demi-plates on the marginal suture bevel over the adradials. Such is the structure on the exterior, but the interior differs markedly. The interior of the ambulacrum

presents a continuous curve corresponding with the rest of the test (Plate 39, figs. 4, 5), instead of being arched up in the center. Demi- and ocluded plates are of about equal width (Plate 43, fig. 4) instead of the ocluded being wider, and pore-pairs are close to the middle line of each half-area instead of lying near to the next adjacent interambulacrum (compare Plate 43, figs. 1, 2, and 3, 4). Demi-plates opposite horizontal interambulacral sutures are broad and fan-shaped. This is not a specific, but a generic and family character, seen also in *Melonechinus* (Plate 56, fig. 5, p. 360).

The interambulacra are wide, and at the mid-zone consist of five columns of plates in each area (Plate 39, fig. 3; Plate 44, figs. 2-4; Plate 46, fig. 4), or occasionally a sixth column in addition may be represented by from one to three or more plates in an area, but in no specimen seen does this extra column occur in all areas (text-fig. 244; Plate 40, fig. 1, area I; Plate 41, fig. 1, areas E, G, I). The adambulacral plates are pentagonal, beveled under the ambulacra on the adradial suture, this inclined face bearing curved facets for articulation with the demi-plates. Ocluded plates on the interior do not touch the adradials, as they do in *Maccoya* (Plate 34, figs. 2, 3). The median columns are composed of hexagonal plates excepting where new columns come in, and also excepting local irregularities as the plates marked P, in text-fig. 244, and Plate 41, fig. 1. The interambulacral plates are thick, but not nearly so much so, or so massive as in the nearly related *Lovenechinus nobilis*. The surface is thickly studded with small secondary tubercles like those of the ambulacra, but spines have not been observed in this species. In the interambulacra ventrally there are two plates in the basicoronal row (Plate 43, figs. 1, 2), above which there are three plates in the second row, and four in the third, the fifth column coming in later at somewhat variable intervals as shown in the figures cited and on Plate 41, fig. 1. In a relatively young specimen (Plate 39, figs. 1, 2; Plate 40, fig. 1) the fifth column in four areas originates near the mid-zone, but there are many fewer rows than in an adult (Plate 41, fig. 1), in which the same column, appearing at about the same age, is pushed adorally in virtue of the fact that many more rows have been added dorsally.

The peristome is unknown. The apical disc is relatively small in the several specimens measured. Its diameter in mature individuals proportionately is about 16 to 18 % of the diameter of the test. In the young individual (Plate 39, fig. 1) the apical disc is proportionately larger, as usual in young Echini, being about 21 % of the diameter of the test. Oculars are usually all insert and cover the ambulacra and laterally the interambulacra in part on either side (Plate 39, figs. 3, 5; Plate 41, fig. 3; Plate 42, fig. 6). As seen in several of the oculars figured, there is on these internal molds an elevated siliceous plug, near the adoral margin, which apparently represents a cast of an ocular pore. An ocular pore has not been seen on the exterior in any species of this family, and whether these pores would have reached the surface is doubtful (p. 89). In one case, the young specimen, two oculars are exsert, being excluded from the periproct by the contact of the two adjacent genitals (Plate 41, fig. 2). The geni-

tals are high, wide, and cover the interambulacra in part in each area. They have from three to five genital pores each, situated below the middle in each plate, and arranged in a semi-circle. There is no trace of a madreporite in any specimen seen (Plate 39, figs. 3, 5; Plate 40, fig. 3; Plate 41, fig. 3; Plate 42, fig. 6). In one specimen there are siliceous molds of a few periproctal plates which are small and angular; they were doubtless numerous, as in other species in this family (Plate 42, fig. 6). Jaws are represented only by indistinct impressions in two specimens (Plate 39, fig. 4).

Burlington Group, Lower Carboniferous, Webb City, Missouri, Museum of Comparative Zoölogy Collection, the holotype, 3,078, and seventeen other specimens 3,124 to 3,141 (all from R. T. J. Coll.); British Museum Collection E 9,554, E 10,679; Coriscana, Missouri, Yale University Museum Collection, three specimens; Carterville, Joplin, Missouri, Museum of Comparative Zoölogy 3,189; F. Braun Collection; Keokuk Limestone, Nauvoo, Illinois, Museum of Comparative Zoölogy Collection 3,197; Burlington, Iowa, F. Springer Collection 8,126.

I have studied altogether some thirty specimens of this species, a richness of material much exceeding that of most known species of Palaeozoic Echini. The more important features of a few of these will now be considered.

The Burlington specimen, in Mr. Springer's collection, is a most instructive and important one. It is one of only two specimens so far found outside of Missouri, and with plates all in place (the other specimen being from Nauvoo, Illinois). The Missouri specimens are siliceous molds. The Burlington specimen is excellent for showing surface characters, especially thickness of plates, curvature of the ambulacra, and external tubercles (Plate 46, fig. 4). These features in this species are otherwise known only from external molds, as Plate 44, figs. 4, 5. There are five columns of interambulacral plates in each area at the mid-zone, and the ventral development of these areas is well shown, there being, as usual in the family, two plates in the basicoronal row, etc. The most interesting feature of this specimen is the perfection of detail shown in the ambulacrum (Plate 42, figs. 1-4), at the mid-zone, and throughout most of the area the typical species character exists as described (Plate 42, figs. 2, 4), with four columns of plates, pore-pairs biserial. Ventrally, near the peristome (Plate 42, fig. 1), the ambulacral plates are primaries with pore-pairs uniserial, like the genus *Palaeochinus*. Higher up, the plates are alternately primaries, crossing the half-area and enlarged marginally, with occluded plates, which meet the center of the area, but are cut off from the interambulacra by the enlargement of their fellows. Pore-pairs are biserial, which is like the character in *Macocya*. Still higher we find that the primary plates have failed to reach the middle of the half-area and are here transformed suddenly into demi-plates, thus assuming the generic character which is maintained thence to the ambitus. We see that in the development of this type it repeats the character of the lower genera in its family in a very complete degree, as set forth also diagrammatically in text-figure 237, p. 231. Looking at the dorsal region (Plate 42, fig. 3),

we see that the younger plates in the placogenous zone close to the oculars are primaries, passing across the half-areas, and pore-pairs are uniserial. This simple condition of the young, last added plates as a localized stage is directly comparable to the plates built in youth (Plate 42, fig. 1), or the plates throughout the whole area in the simpler genus *Palaeochinus* (Plate 31, fig. 1). Passing ventrally from the youngest plates to those somewhat older and structurally more advanced, although there is some irregularity, we see that at the zone marked X, X, in Plate 42, fig. 3, the plates for a short distance are alternately primaries, which are expanded at the adradial suture, and occluded plates, which are cut off from the adradial suture, but both meet the center of the area, and pore-pairs are biserial. This is like the second stage in development seen ventrally, and like the character of *Maccoya*, the next lower genus in which ambulacral plates are typically primary and occluded with pore-pairs biserial (Plate 33, fig. 7). Thus, from ventral developing stages and from dorsal localized stages in a single specimen can be read the relations of the type to associated genera in the family. But this is not all that is shown by this wonderful specimen. At the point marked *y*, in the left half-area (Plate 42, fig. 3), there are two plates, and at *y* in the right half-area there is one plate, which lie in the middle of the half-areas and do not reach either the adradial suture or the middle of the area. In other words, these are sporadic cases of isolated plates, and the only ones seen in any specimen of the genus. As a character, they represent local progressive variations toward just that addition of plates which is the character of *Oligoporus*, and is the beginning of the system of isolated plates which is the main feature of *Melonechinus*.

A young specimen in the Museum of Comparative Zoölogy Collection 3,140, which is only 32 mm. in diameter (Plate 39, figs. 1, 2; Plate 40, figs. 1, 2; Plate 41, fig. 2), is of much interest as the youngest Palaeozoic echinoid seen. It is so nearly complete that with some restoration, indicated by dotted lines, it is drawn spread out by the Lovén method (Plate 40, figs. 1, 2). There are two plates in the basicoronal row as restored, three in the second row, observed or inferred, and four in the third row, as observed or inferred. The fifth column originates in the fifth to the eighth row in four areas, but in area E this column is apparently represented by only a single plate, which is in the thirteenth row. A sixth column is represented by a single plate dorsally in the thirteenth row in area I. As it is a young specimen, there are fewer plates than in an adult, there being only 13 or 14 plates in each adradial column in four of the areas, but in area E, which is much narrower, there are 15 adradial plates on each side. This area in the drawing of the internal mold is restored ventrally, but a good deal of this portion is shown in Plate 40, fig. 2, drawn from a wax cast of the external mold, which therefore supplements for this area the less complete drawing of the interior. In a large adult (Plate 41, fig. 1) there are from 25 to 27 plates in each adradial column, about twice as many as in this young specimen. (Compare studies of the interambulacrum, Jackson, 1899, p. 129.)

In a dorsal view of this young specimen (Plate 41, fig. 2) oculars B, J, and probably H,

are broadly insert, but oculars D and F are exsert. This is the only case of exsert oculars seen in the species. Ventrally, the oculars bear each a small siliceous plug, representing a cast of the ocular pore, which probably did not reach the surface, as such have not been seen on the surface in any species of this family. The oculars ventrally cover the ambulacra and laterally the interambulacra in part on either side. The apical disc measures 7 mm. in diameter and is proportionately about 21 % of the diameter of the test. This is proportionately large for the species and family, but evidently, as in Recent Echini, the apical disc is proportionately larger in young individuals (p. 87). In this dorsal view the single plate representing the sixth column is clearly seen in area I.

In Mr. Braun's specimen (Plate 39, fig. 3; Plate 41, fig. 3), from Joplin, Missouri, we have an internal siliceous mold about 58 mm. in diameter and nearly spherical. It has five columns of plates in each interambulacral area, but dorsally the fifth column is strung out, and in areas A, C, and E fails to reach the apical disc (Plate 41, fig. 3). Oculars are all insert, and ventrally cover the ambulacra and laterally the interambulacra in part on either side. The genitals are wide, high, and have four or five genital pores each. Dorsally, in this internal mold, ambulacral plates are all primaries, with pore-pairs uniserial; farther ventrally they are primaries and occluded, with pore-pairs biserial (compare Plate 42, fig. 3).

A magnificent specimen in the Museum of Comparative Zoölogy Collection 3,128, from Webb City, Missouri, is one of the finest Palaeozoic Echini seen. It is an internal siliceous mold, and is represented in ventral and dorsal views in Plate 39, figs. 4, 5. The boundary of *each plate* is represented by a siliceous ridge, so that, if plates have been separated, there is an independent bounding ridge for each plate, as seen well in area E (Plate 39, fig. 5). Siliceous plugs represent the ambulacral and ocular pores and delicate siliceous tubes the casts of the larger genital pores. The specimen is somewhat compressed, but averages about 95 mm. in diameter. It is not only full grown, but is an old-age individual, as indicated by the dropping out of columns dorsally, as described below.

So nearly complete is this specimen that I am able to represent it spread out by the Lovén method (Plate 41, fig. 1), with the restoration of only a few plates ventrally, as indicated by dotted lines. The ambulacral plates at the mid-zone are demi- and occluded, with pore-pairs biserial, but situated on either side in the middle line of each half-area (compare Plate 42, figs. 2, 3; Plate 43, figs. 4, 5). The ambulacral plates near the peristome, which were built in youth, and the young plates dorsally, near the ocular, as a localized stage, are primaries, crossing the half-areas, and with pore-pairs uniserial (compare Plate 42, figs. 1, 3).

In the interambulacra (Plate 41, fig. 1) there are two plates in the basicoronal row, in part restored, three plates in the second row, also partially restored, four plates in the third row, restored in two areas. The fourth column originates on the left of the center in areas A and C, but apparently (in part restored) to the right of the center in E, G, and I. There are a good

many local peculiarities in this choice specimen which I will now describe. In area A the fifth column originates in a pentagon in the eighth row, with a heptagonal plate on its right ventral border, as usual. In the ninth row there are only four plates, one being a large octagonal plate, O, whose two extra sides are compensated for by a pentagon above it marked 5, where the fifth column starts again, and another pentagon, P, below it. Octagonal plates are very rare. In area C the fifth column originates on the left of the center with a pentagonal plate having a heptagon in its right ventral border. In the eighth row there is an adventitious pentagon, P, in which the side wanting is compensated for by an adjacent heptagonal plate. In areas E and G the fifth column originates in the sixth row, with a heptagon on the right ventral border, as usual, and in area I it originates in the seventh row, with a heptagon on its right ventral border. In areas A and C there are only five columns of plates, but in the other areas a sixth column is represented by one or two plates in each. In areas E and I a sixth column is represented by one pentagonal plate in the thirteenth or the eleventh row, with a heptagon on its left ventral border. In addition, as a peculiarity, in each area an adventitious pentagon, P, lies on the left of pentagon 6, and to compensate for the one side wanting, a heptagonal plate, H, lies on the dorsal border of the pentagons. In area G the sixth column is represented by two plates, a pentagon in row 11 and an overlying hexagonal plate. A heptagonal plate lies on the left ventral border of the initial pentagon. In addition, as a peculiarity, an adventitious pentagon, P, lies on the right side of hexagon 6, and to compensate for its one side wanting, a heptagon lies on its dorsal border, as in areas E and I. Passing dorsally, column 5 drops out before reaching the apical disc, as seen more clearly in Plate 42, fig. 6. In Plate 41, fig. 1, the plates are drawn representing the character as seen on the proximal or interior aspect of the test, and here all the adambulacral columns extend to the apical disc. As viewed superficially, however, a somewhat different condition occurs, as shown in Plate 39, fig. 5; Plate 42, fig. 6. Taking area I as the best example, on the left and right we see the silicified marginal walls of ambulacra J and H, beveling over interambulacrum I. The plates of the adambulacral columns 1 and 2 are existent, but do not reach the surface, being roofed over, or occluded, by the lateral borders of the plates of columns 4 and 3, which alone meet the ambulacra laterally near the surface of the test. This is explained by the diagram (Plate 42, fig. 7), in which on the interior of the test there are five interambulacral plates, but on the exterior only three, as plates of columns 3 and 4 roof over and shut out plates of columns 2 and 1, which therefore meet the ambulacra proximally, but not distally. A similar shutting out of plates quite probably occurs in such a case as Plate 53, fig. 1. A comparable shutting out of plates by occlusion occurs more or less completely in the other areas of the specimen (Plate 42, fig. 6).

Dorsally all oculars are in place (Plate 39, fig. 5; Plate 42, fig. 6). The apical disc measures about 16 mm. in diameter, being about 16 % of the diameter of the test which is

relatively smaller than in the young individual (p. 342). Oculars are insert, ventrally cover the ambulacra, and laterally the interambulacra in part on either side. Two of the oculars show pores ventrally as indicated by siliceous plugs like those previously described. The genitals are high, wide, with three or four pores each. These are represented by delicate siliceous tubes which were evidently formed as post-mortem linings to the original pores and before the solution of the plates. A few molds of periproctal plates are in place (Plate 42, fig. 6); they are small, angular, as in other species in the family, and are the only ones yet known in this genus. Impressions of jaws are imperfectly seen ventrally (Plate 39, fig. 4).

A specimen that I gave the British Museum, now no. E 10,679 of its collection, is a large individual measuring 83 mm. in diameter. It is a dark brown, silicified internal mold from near Webb City, Missouri. The ambulaeral plates are demi- and occluded at the mid-zone, but primaries only close to the oculars. In three interambulaeral areas, A, C, and G, there are six columns of plates. In each the sixth column is represented by a considerable number of plates, more than in any other specimen of the species seen. The exact number could not be ascertained as the point of origin of this column is not preserved in any area, but in area G a sixth column is represented by at least ten plates, above which it drops out, and there are five columns; and far dorsally, another column drops out, so that only four columns are in contact with the apical disc, as in area E of Plate 41, fig. 3. Dorsally molds of the five oculars are in place, all are insert, and ventrally cover the ambulacra and laterally the interambulacra in part on either side. The genitals are high, wide, with several pores each, but details of the pores are imperfect.

A specimen from Coriscana, Missouri, in the Yale University Museum Collection, is well preserved and is practically spherical (Plate 44, fig. 2), measuring 59 mm. in height, 62 mm. in diameter through the mid-zone in the view shown, and also 59 mm. in diameter in the same plane, but at right angles to that figured. The specimen is an internal siliceous mold and shows the impression of plates clearly. There are five columns of plates in each interambulacral area at the mid-zone, and in no area is a sixth column developed. The oculars are all in place and insert; genitals are high, wide, with three pores in two of the plates, five pores in two, and in one genital the pores are indistinct. Another specimen from Coriscana in the Yale Collection, no. 313, is very large and somewhat elongated by compression. It measures 114 mm. in height, 101 mm. in diameter through the mid-zone in one plane, and 76 mm. in diameter through a plane at right angles to the same. There are five columns of plates in all the interambulacral areas, though one area is obscure at the mid-zone. The genitals are high, wide, two with three genital pores, two with four, and one with five pores.

A choice specimen from Webb City, Missouri, in the Museum of Comparative Zoölogy Collection, no. 3,125, has on one side a siliceous mold of the interior and on the other a siliceous mold of the exterior, the spaces originally occupied by the plates being hollow (Plate 44, figs. 3,

4). The internal mold has impressions of the proximal faces of the plates, ridges representing bounding lines, and siliceous filaments which are casts of ambulacral pores. The external mold has impressions of the outer or distal faces of plates with tubercles, ridges representing bounding lines of plates, and siliceous filaments which are casts of ambulacral pores as in the inner mold. By studying the internal mold, and wax impressions made from the external mold, it is possible to compare the external and internal characters of the same plates as if seen in optical section (Plate 43, figs. 1-4). The ambulacrum seen from the exterior at the mid-zone (Plate 43, fig. 3) has four columns of plates, wide ocluded and narrower demi-plates, with pore-pairs biserial and situated in the outer end of each plate, near the marginal suture. Two rows of tubercles are on the ocluded, and a single tubercle on the inner tongue of the demi-plates. On the proximal or inner side of the very same plates (Plate 43, fig. 4), the ocluded and demi-plates are of about equal width. Demi-plates opposite horizontal interambulacral sutures are higher and fan-shaped, and pore-pairs lie near the middle of the half-area. This passage of pore-pairs from the middle to the outer margin of the area, in traversing the thickness of the plates, is shown graphically in a unique bit of preservation (Plate 43, fig. 5), in which we find proximally a mold of the interior, distally a mold of the exterior, and the pores represented by slender siliceous filaments which traverse the hollow space originally occupied by the plates. It is here seen that the filaments are strongly inclined laterally, being near the middle of the area proximally, but close to the outer margin of each plate distally. Ventrally, in the basicoronal row, as seen from the exterior (Plate 43, fig. 1), the ambulacral plates are all primaries, and pore-pairs uniserial, lying close to the marginal sutures. On the interior at the same zone (Plate 43, fig. 2) the ambulacral plates are also primaries, but the pore-pairs are about in the middle of the half-areas. Passing dorsally, on the exterior at the zone marked X (Plate 43, fig. 1), the plates are alternately primaries, expanded marginally, with those between narrowed and nearly or quite ocluded, pore-pairs biserial, as in *Maccoya*. On the interior at the same zone marked X in Plate 43, fig. 2, the plates are still all primary, with pore-pairs uniserial, again like *Maccoya*, but as seen from the interior (Plate 33, figs. 8, 9). Again passing dorsally, on the exterior at the zone marked XX (Plate 43, fig. 1) the plates are demi- and ocluded, the genus character. On the interior at the same zone, marked XX (Plate 43, fig. 2), the plates are primary and ocluded. They have therefore not yet taken on the character as seen on the exterior, but have lagged behind in development, and are like the more ventral plates of the exterior, and again like the typical plates on the exterior of *Maccoya*. This close comparison that can be drawn by stages in development, as seen in plates ventrally, built in youth, and the greater primitiveness of plates on the proximal side as compared with the distal side, with the simpler characters of lower genera in the family, is all in favor of the recapitulation theory in evolution. Abundant similar cases are found throughout the Echini, supporting the same view in the strongest way.

In the interambulacra of this choice specimen there are five columns of plates at the mid-zone, in all five areas. Ventrally, there are two plates in the basicoronal row in all areas (Plate 43, figs. 1, 2), three plates in the second, and four plates in the third row. The fourth column originates on the right of the center in areas A, C, and E; but on the left of the center in areas G and I. In area A the fifth column originates as a pentagon in the sixth row, with a heptagon on its right ventral border. In area I the fifth column originates also in the sixth row, but by rare exception the initial plate is tetragonal, and to compensate for its two sides wanting, there is a heptagonal plate, H, on its right ventral border and another on its left border. The interambulacral plates on the exterior (Plate 43, fig. 1), as usual, bear numerous small, secondary tubercles. These tubercles are shown on the external mold (Plate 44, fig. 4), and especially clearly on another external mold (Plate 44, fig. 5).

The character of primary plates ventrally, passing into four columns dorsally, as seen from the interior, is shown in Plate 39, fig. 6, and Plate 42, fig. 5. There is, however, some confusion ventrally in area B, and the series is not so complete as in the cases previously described.

***Lovenechinus anglicus** sp. nov.

Plate 46, figs. 5, 6; Plate 47, figs. 3-5.

¹ *Palaeochinus gigas* Duncan, 1889, p. 198, text-fig. i; Jackson, 1896, p. 204, Plate 7, figs. 38, 39.

² Non *Palaeochinus gigas* M'Coy, 1844; non Baily, 1874, p. 41, Plate 3, figs. a-d; non Keeping, 1876.

² Non *Palaeochinus gigas* Lovén, 1874, p. 41.

² Non *Maccoya gigas* Pomel, 1883, p. 115; non Lambert and Thiéry, 1910, p. 119.

¹ *Paleochinus gigas* Tornquist, 1897, p. 739.

¹ *Palaeochinus gigas* (pars) Klem, 1904, p. 32.

The specimen on which this species is based, in the Museum of Practical Geology Collection 6,576, is apparently that of which Professor Duncan figured the ambulacrum as *Palaeochinus gigas*, and I also figured it as the same species. The structure of the ambulacrum of *Palaeochinus gigas*, however, is entirely different, being composed of primary and occluded plates, all of which meet the middle of the half-area (Plate 47, figs. 1, 2). The great size of the interambulacral plates, and also the original label, which reads *Palaeochinus gigas*, probably misled Professor Duncan when he described it.

This specimen is in many respects very perfectly preserved, but is somewhat remarkable for the peculiarities by which portions of the test are shown (Plate 46, fig. 5). In interambulacrum A there are five columns of plates in place and a vacancy on the right for at least one additional column, which would be a right pentagonal adradial. Ambulacrum B is represented

¹ The several references included in these paragraphs are based on the specimen here described as *Lovenechinus anglicus* and which Duncan erroneously referred to *Palaeochinus gigas*, see pp. 304, 321.

² The several references included in these paragraphs refer to the true *Palaeochinus gigas* of M'Coy, here referred to *Maccoya gigas*, p. 321.

by the right half-area only. The left half of ambulacrum B and the right portion of interambulacrum C have been pushed under areas A, B so as to be quite hidden from view. Interambulacrum C is represented by the left adradial and one adjacent median column of hexagonal plates. Of ambulacrum D, the whole width of the area is in place, though not very clearly seen. Interambulacrum E has six columns of plates, as can be seen dorsally, although they are somewhat displaced.

A complete test is unknown; but the shape as preserved indicates that the entire specimen was probably spheroidal, and the size of the plates shows that the whole specimen must have been very large, one of the largest of known Palaeozoic Echini. The height of the specimen as it exists is 115 mm., and the width 150 mm. The half ambulacrum B measures 7.5 mm. in width, therefore the whole area would measure 15 mm. in width. Interambulacrum A measures 55 mm. in width. Adding one adambulacral column on the right (as this at least is wanting), the width on the basis of six columns would be about 65 mm. Assuming 15 mm. for the width of the ambulacrum, and 65 mm. for the interambulacrum, the circumference would be about 400 mm. and the diameter about 127 mm. The interambulacral plates are very large, the pentagonal adradials measuring up to 11 mm. in width by 8 mm. in height, and the largest hexagonals 12 to 13 mm. in width by 8 mm. in height. With this great areal size they are relatively very thin, about 2 mm. in thickness.

The ambulacra are relatively narrow, with four columns of plates throughout most of the area, there being two columns of wider ocluded and two of narrower demi-plates in each half-area (Plate 47, figs. 3, 5). The outer ends of the ocluded plates fit between the inner tongue-like extensions of the demi-plates as in *Lovenechinus missouriensis*. The pore-pairs are in well marked peripodia and are biserial in arrangement, each pair situated in the outer ends of the ocluded and demi-plates as usual in the genus. About four demi-plates equal the height of an adradial. The extreme ventral part of the test is unknown, but as far ventrally as preserved in area D (Plate 47, fig. 4) all ambulacral plates meet the middle of the half-area, but alternate plates are primaries expanded marginally, and ocluded or cut off from interambulacral contact by enlargement of their fellows. This character is like that typical of adult *Maccoya* (Plate 33, fig. 7), and also like that seen as a second stage in development in *Lovenechinus missouriensis* (Plate 42, fig. 1). On the reverse side of the specimen are several excellent fragments of ambulacra seen from the interior of the test. In these the demi- and ocluded plates are of about equal width, and the pore-pairs lie near the middle of the half-areas, as seen in the internal view of *Lovenechinus missouriensis* (Plate 43, fig. 4).

The interambulacra are very wide, composed of probably six columns in each area. In area A (Plate 47, fig. 3) the left adambulacral column of pentagonal plates is in place, and also four columns of hexagonal plates. I have indicated by dotted lines a right adambulacral column which probably would complete the area. Six columns can be made out dorsally in

area E of the photographic figure (Plate 46, fig. 5). In area A ventrally, the initial plate of column 6 is seen as a pentagon with a heptagon on its left ventral border. Ambulacral and interambulacral plates alike bear small secondary tubercles with some minute tubercles between them. Many small, slender, tapering spines up to about 3 mm. in length are borne on both ambulacral and interambulacral plates (Plate 46, fig. 6). The dorsal part of the test is quite unknown. I am indebted to Dr. Kitchin of the Museum of Practical Geology for the excellent photograph of this species, which he kindly had taken for me by Mr. J. W. Tutchér.

Lower Carboniferous, Clitheroe, Lancashire, holotype and only known specimen, Museum of Practical Geology, London, no. 6,576.

****Lovenechinus septies* sp. nov.**

Text-fig. 17, p. 59; Plate 44, figs. 6, 7; Plate 45, figs. 1-6.

The test is small, spheroidal, with remarkably perfect detail in the type, but crushed. Width of the ambulacra at the mid-zone 8.5 mm., of the interambulacra at the same zone 18 mm. Diameter in the neighborhood of 50 mm., but from the crushing it cannot be very closely stated.

Ambulacra at the mid-zone and throughout most of the areas with four columns of plates, wide occluded and narrow demi-plates in each half-area (Plate 45, figs. 1, 3). The occluded plates laterally fit into the inner angles of the demi-plates, but with serrate, not tongue-like extensions (as in *L. missouriensis*, Plate 42, fig. 2). Pore-pairs are biserial, situated in the outer portion of each ambulacral plate. The ambulacral plates bevel over the adradials, and the occluded plates rise in a high arch which is formed by the median thickening of these plates (Plate 45, fig. 5). Ambulacral plates ventrally and dorsally are primaries, as later described in detail. Interambulacra at the mid-zone are wide, with six columns of plates, but a seventh appears dorsally in each area (Plate 45, fig. 1). The adambulacrals are pentagonal, others hexagonal as usual. Two interambulacral plates are in the basicoronal row in most areas, above which additional columns appear as usual in the family, as later described in detail. Small secondary tubercles occur alike on ambulacral and interambulacral plates, but no spines are preserved. Dorsally, the apical disc is crushed in, but can be made out in part. Oculars are insert, imperforate, and adorally cover the ambulacra and laterally in part the interambulacra on either side. Genitals are high, wide, with two and probably more pores each.

This species differs from others of the genus in having more columns of interambulacral plates; also the contact of occluded and demi-plates differs from that of other species excepting *L. mutatus*, where the interlocking of these plates is closely similar. The holotype is in Mr. Frank Springer's collection and was received by him from Professor G. Hambach of St. Louis, Missouri.

Warsaw Group, Lower Carboniferous, Boonville, Missouri; holotype in F. Springer's

Collection, no. 8,115; also three additional incomplete specimens from the same locality and in the same collection.

Although crushed, the type specimen is so completely preserved that I am able to represent it spread out by the Lovén method (Plate 45, fig. 1), and it presents interesting developmental characters in both the ambulacra and the interambulacra. Ventrally, for a short distance, ambulacral plates are primaries (Plate 45, fig. 2), above which follow primary and demi-plates immediately, and these again are shortly followed by the typical ocluded and demi-plates characteristic of the type. No stage of primary and ocluded plates (such as occurs in *Lovenechinus missouriensis*, Plate 42, fig. 1) was found in this species, and it has apparently been skipped by acceleration of development. This is interesting, for in other characters it is the highest species in the genus, and it is in just such a case of highest species that acceleration is most marked, as shown by Hyatt. Dorsally, close to the oculars (Plate 45, fig. 4) high, narrow primary plates exist as a localized primitive stage, but, passing adorally, they quickly change into the characteristic four columns of demi- and ocluded plates.

The interambulacra with only slight reconstruction (indicated by dotted lines) are shown throughout each area (Plate 45, figs. 1, 2). Ventrally, in each area (excepting C and G, in which they are restored) there are two plates in the basicoronal row and three plates in the second row. In four areas the initial plate of column 3 is hexagonal as usual, with the initial pentagon of column 4 in the next succeeding row. In area C, however, there are two rows of three plates each before column 4 originates in the fourth row. As a result of this difference, the initial plate of column 3 is pentagonal and the succeeding plate is heptagonal, having one side added to compensate for the one side short in pentagon 4 (p. 68). A similar case of this rare variation of a later introduction of column 4 with coincident modifications in the angles of associated plates is seen in *Palaeochinus quadriserialis* (p. 307; Plate 30, fig. 3, area C). In *L. septies* (Plate 45, fig. 1) the fourth column originates on the right of the center in areas A and E, but on the left of the center in areas C, G, and I. The fifth column originates with a pentagon in the middle in all areas. In areas A and E it originates in the sixth row with a heptagon on the right ventral border, in G and I in the sixth row with a heptagon on the left ventral border, and in area C in the seventh row with a heptagon on the left ventral border. The sixth column originates with a pentagonal plate in the tenth or twelfth row in each area. It originates in areas A and G in the twelfth row on the right of the center with a heptagon on the right or left ventral border; also in area C it originates in the twelfth row, but on the left of the center, and with a heptagon on its right ventral border. In areas E and I the sixth column originates in the tenth row, on the left of the center with a heptagon on the right ventral border. The seventh column originates with a pentagonal plate in the middle of each area, with a heptagonal plate on the ventral border. In three cases, areas E, G, and I, the heptagon lies on the right, and in two cases, areas A and C, on the left of the initial pentagon. The

seventh column originates in the sixteenth to the nineteenth row in the several areas. In area A it appears in the eighteenth row; in C in the nineteenth row; in G in the seventeenth row; and in areas E and I in the sixteenth row. It is worth noting that in areas E and I, in which the seventh column originates earlier than in the others, column 6 also originates earlier, showing an acceleration in both features. Also, in area C columns 4, 5, and 7 all originate later than in the other areas, showing a corresponding retardation of development in those several features (p. 50). Dorsally in part, as shown in area C, the adambulacral columns 1 and 2 drop out before reaching the apical disc, indicating senescence.

OLIGOPORUS Meek and Worthen.

Oligoporus Meek and Worthen, 1860a, p. 472; 1866, p. 247; (pars) Lovén, 1874, p. 42; Duncan, 1889a, p. 16; (pars) Jackson, 1896, p. 239; (pars) Lambert and Thiéry, 1910, p. 121.
Melonopsis Meek and Worthen, 1866, p. 249.

The test is spheroidal, with more or less strongly developed melon-like ribs. Ambulacra at the mid-zone with four columns of plates which consist of two columns of wide ocluded and two columns of narrower demi-plates, with, in addition, scattered isolated plates in the middle line of each half-area, but not of sufficient frequency to constitute an additional column. The wide ocluded plates are roundly arched upward in the center. The pore-pairs are multiserial, one series in each column of demi- and ocluded plates, and, in addition, a broken series in the scattered isolated plates.

The interambulacra are wide, with from four to nine columns of plates in an area in the known species. The columns are composed of pentagonal adradial and hexagonal median plates. There are ventrally two plates in the basicoronal row, above which additional columns come in as usual in the family. There is no imbrication in ambulacral or interambulacral plates, but the ambulacrals bevel over the adradials laterally. Ambulacral and interambulacral plates bear small secondary tubercles with small tapering spines. Peristome unknown. Apical disc imperfectly known, but doubtless similar to that in *Melonechinus* with insert, imperforate oculars and high, wide genitals bearing several genital pores each. Lantern known partially in *O. danae*, from which it is seen that the lantern was inclined, pyramids wide-angled with moderately deep foramen magnum as usual in the *Perischoechinoida*.

The type species of the genus is *Oligoporus danae* (Plate 49, figs. 4, 5; Plate 47, fig. 13; Plate 50, figs. 1-12).

Oligoporus differs from *Lovenechinus* in that it has scattered isolated plates in the ambulacra in addition to the four columns of demi- and ocluded plates. Thus it is a step in advance in the evolution of this important structure. In the interambulacra it is also more advanced in that the highest species (*danae*) has nine columns of interambulacral plates in an area, whereas

in *Lovenechinus* the highest known species (*septies*) has only seven columns in an area. *Oligoporus* differs from *Melonechinus*, as in that genus the isolated plates are sufficiently numerous so that they form one or more irregular columns of plates between the demi- and occluded plates in each half-area. *Melonechinus* is also more evolved in the interambulacrum in that the highest species has eleven columns of interambulacral plates, whereas the highest species of *Oligoporus* has but nine. In the development of the ambulacrum ventrally, *Oligoporus* passes through a stage in which the plates are like *Lovenechinus* at the mid-zone; and *Melonechinus* in the development of its ambulacrum ventrally passes through stages in which the plates are successively like *Lovenechinus*, then like *Oligoporus* at the mid-zone (text-fig. 237, p. 231). Thus both the structure in adults and the progressive stages in development unite these genera into a phylogenetic whole.

*Key to the Species of Oligoporus.*¹

Interambulacra with six or seven columns of plates in an area (in one area of one specimen, as an exceptional arrested radial variation, there are four columns only); melon-like ribs moderately developed

O. blairi Miller and Gurley, p. 351.

Interambulacra with seven columns of plates in an area, or in part with six columns only; melon-like ribs strongly elevated and rounded in outline *O. coreyi* Meek and Worthen, p. 353.

Interambulacra with seven columns of plates in an area; melon-like ribs strongly elevated and sharply rounded; interambulacra dipping steeply down to adradial sutures *O. sulcatus* Miller and Gurley, p. 354.

Interambulacra with eight or seven columns of plates in an area *O. halli* sp. nov., p. 355.

Interambulacra with nine columns of plates in an area *O. danae* (Meek and Worthen), p. 356.

****Oligoporus blairi* Miller and Gurley.**

Plate 47, figs. 6, 7; Plate 48, fig. 1; Plate 49, figs. 1-3.

Oligoporus blairi Miller and Gurley, 1893, p. 6, Plate 1, figs. 2, 6; Plate 2, fig. 7; Lambert and Thiéry, 1910, p. 121.

Oligoporus bellulus Miller and Gurley, 1893, p. 7, Plate 1, fig. 3; Lambert and Thiéry, 1910, p. 121.

Oligoporus danae (pars) Klem, 1904, p. 37.

The test is spheroidal, with moderately developed melon-like ribs. In one specimen (Plate 49, fig. 1) the ambulacra measure 12 mm., the interambulacra 21 mm. in width. In a second specimen (Plate 49, fig. 3) the ambulacra measure 12 mm. and the interambulacra 18 mm. in width.

The ambulacra are relatively wide, having at the mid-zone four columns of narrow demi- and wider occluded plates, also some scattered isolated plates in or near the middle of the half-areas. Occluded plates are elevated in a low rounded median ridge; pore-pairs are near the outer border of each ambulacral plate.

¹ The species described as *Oligoporus* (?) *minutus* is considered under *Incertae Sedis* (p. 450).

Interambulacra broad, elevated in a moderate curve from the adradial sutures, with six or seven columns of plates in each area. In one specimen (Plate 48, fig. 1) one area, A, as an exception is very narrow, and has four columns of interambulacral plates, but the next adjacent area, C, has seven columns. This specimen, on account of the four columns in one area, was considered a distinct species by Miller and Gurley, and described as *Oligoporus bellulus*. The ventral and dorsal portions are unknown. Ambulacral and interambulacral plates bear small secondary tubercles, and one specimen has numerous small tapering spines about 2.5 mm. in length.

The specimen which Miller and Gurley described as the type of *Oligoporus bellulus* (Plate 47, fig. 6; Plate 48, fig. 1) I feel is nothing more than a very peculiar exception. The ambulacrum and interambulacrum C with seven columns are quite normal for the species. The interambulacrum A is certainly very exceptional in having only four columns; no such range in two areas of one individual has been seen in any other specimen in this family. It may, however, better be considered an extreme arrested variant in this one area rather than as a basis for a distinct species. I therefore consider *bellulus* a synonym of *blairi*. Miller and Gurley do not mention that there are seven columns in one of the areas of this specimen. It has numerous small spines as described above.

One of Miller and Gurley's cotypes of *blairi* (Plate 47, fig. 7; Plate 49, fig. 1) represents a considerable part of the dorsal half of a test. It is perhaps the most characteristic of all the specimens. The interambulacra A and C have each seven columns of plates. Miller and Gurley give six columns as the species character, but do not mention a seventh. I do not quite understand how they overlooked this feature. This specimen shows the surface form of the areas better than any other.

A second cotype (Plate 49, fig. 3) represents about the middle of the corona. In area A there are six columns of plates; ventrally the initial pentagonal plate of column five is seen in the middle line and in the second row from the base. The initial pentagon of column six is seen in the sixth row from the base, and a heptagonal plate lies on its right ventral border. In area C there are six columns of plates and indications of a seventh column as shown by the pentagon, with a heptagonal plate on its right ventral border lying 30 mm. from the base of the specimen and with three columns of interambulacral plates lying between this pentagon and ambulacrum D.

The third cotype of *blairi* and the smallest specimen (Plate 49, fig. 2) has six columns of interambulacral plates in area A. The initial plate of the sixth column is a pentagon with a heptagon on its left ventral border and lying just below the middle of the area. In area C there are seven columns of interambulacral plates. The initial plate of column 5 lies 7 mm. above the ventral border of the specimen, and there is a heptagonal plate on its right ventral border. Three rows above appears the initial pentagon of column 6, with a heptagon on its

right ventral border. Three rows higher again appears the initial plate of the seventh column with a heptagon on its left ventral border.

This species is very close to *Oligoporus coreyi*; but apparently differs from that species in the less pronounced and less sharply elevated ribs in the ambulacral areas. It is very distinct from *Oligoporus danae* of which it was treated as a synonym by Miss Klem. Through the kindness of Professor Stuart Weller, I have been able to study all of the original material and give figures of the same.

Keokuk Group, Lower Carboniferous, Boonville, Missouri, cotypes, three specimens in the University of Chicago Collection 6,470; same locality, an additional specimen (which is the holotype of *Oligoporus bellulus*) University of Chicago Collection 6,190; Keokuk Group, Bono, Lawrence County, Indiana, Museum of Comparative Zoölogy Collection 3,188.

****Oligoporus coreyi* Meek and Worthen.**

Plate 47, figs. 8, 9; Plate 48, fig. 2.

Oligoporus coreyi Meek and Worthen, 1870, p. 34; Lovén, 1874, p. 42; Keyes, 1895, p. 183; Jackson, 1896, p. 189, text-fig. 1, p. 191, Plate 6, figs. 25, 28, 29; Klem, 1904, p. 38; Lambert and Thiéry, 1910, p. 121.

The type specimen is silicified and beautifully preserved as regards form, although not very clear in detailed structure, as it is worn, and the test is somewhat compressed. Test spheroidal, with strong, rounded, elevated melon-like ribs in both ambulacral and interambulacral areas. Height 40 mm.; this measurement would be greater if the specimen had not been compressed. Diameter at the mid-zone through the plane B, G, 58 mm.; through the plane D, I, 59 mm. The measurements of the diameter are somewhat exaggerated by the dorso-ventral compression of the test. The ambulacra at the mid-zone measure about 12 mm. in width and the interambulacra about 20 mm. in width.

The ambulacra could not be made out satisfactorily at the mid-zone, but in the mid-dorsal region (Plate 47, fig. 9) there are four columns of demi- and ocluded plates. These are of about equal width, a usual character dorsally; but at the mid-zone the ocluded are probably wider than the demi-plates. In addition, there are some scattered isolated plates that do not reach either the middle of the area or the interambulacra, which is the generic character. Pore-pairs are in deep sunken furrows, lying in the outer border of each plate. The ocluded plates in the middle are arched up in a high rounded melon-like curve.

The interambulacra just above the mid-zone have seven columns of plates in areas A, E, and G. In area C there are only six columns, and in I there are six columns, and possibly seven, but this area is not clear dorsally. The seventh column comes in a little dorsal to the mid-zone, and at that zone, strictly speaking, there are six columns of plates in all areas. The

surface ornamentation is not preserved, but it doubtless bore small secondary tubercles as in related species. The ventral portion and apical disc could not be ascertained in the type.

A specimen in the Museum of Comparative Zoölogy Collection 3,008, which I described previously (1896) and referred to this species, is an internal view. Ventrally, the ambulacral plates are not very well preserved, but are seen to cross the half-area. Higher up the plates are in four columns, demi- and ocluded, and the pore-pairs are in the middle of the half-areas, as seen on the interior of *Lovenechinus*. In the interambulacrum there are two plates in the basicoronal row, three plates in the second row, and four in the third. The fifth column comes in in the sixth row, and as seen in another area, the sixth column comes in three rows above the fifth, apparently in the ninth row. This specimen is preserved as calcite plates in a clay matrix, stained yellow with iron. The locality given on the label is Indiana, and Mr. Springer informs me that material of this character occurs at Crawfordsville, so that the specimen probably came from that locality or its vicinity.

This species is very close to *blairi* and *sulcatus*; the difference from *blairi* is its more strongly elevated melon-like ribs, and the difference from *sulcatus* is the sharply angular character of the interambulacral areas of that species where they dip down to the adradial sutures. These differences are slight, but they are sufficient, it seems, to maintain these as distinct species, although in the number of columns of interambulacral plates they are practically identical.

The specimen which I identify as the holotype is in the University of Michigan Collection 147, from the Keokuk beds of Crawfordsville, Indiana. It bears the locality and identification in Meek's handwriting, and corresponds with the original description in essential features, so that it is undoubtedly the type; another specimen from Crawfordsville is in the British Museum Collection E 4,273. A third specimen, in the Museum of Comparative Zoölogy Collection 3,008, as described above, and probably from the same locality, is the only other known specimen of the species.

****Oligoporus sulcatus* Miller and Gurley.**

Plate 47, fig. 10; Plate 48, figs. 3, 4.

Oligoporus sulcatus Miller and Gurley, 1893, p. 8, Plate 1, figs. 4, 5; Lambert and Thiéry, 1910, p. 121.

Melonites multiporus (pars) Klem, 1904, p. 43.

The specimen is silicified, test high, spheroidal, with strongly marked and quite angular melon-like ribs in ambulacral and interambulacral areas. The holotype, which is the only known specimen, measures 53 mm. in height, and 65 mm. in diameter through the mid-zone, in the plane J, E. Ambulacra measure 13.5 mm. in width, interambulacra 25 mm. in width at the mid-zone. The surface detail is corroded and gone in parts, especially ventrally, as seen in the photographic figures, but the essential specific features can be ascertained. The ambulacra at the mid-zone (Plate 47, fig. 10) consist of four columns of narrower demi- and

wider occluded plates, with scattered isolated plates in the middle line of each half-area. The occluded plates are medially rounded up in a high, steeply arcuate ridge. Pore-pairs are in deep, sunken valleys, lying in the outer border of each ambulacral plate.

The interambulacra are wide, strongly elevated in melon-like ribs, which outwardly present a gently rounded curve, but laterally dip suddenly down to the adradial sutures. At the mid-zone in each area there are six columns of interambulacral plates, but just above the mid-zone, a seventh column appears in each area. As noted by Miller and Gurley, part of the columns drop out dorsally before reaching the apical disc, indicating senescence. Traces of insert ocular and genital plates appear dorsally. This species is close to *blairi* and *coreyi*, but differs from them, as discussed under *coreyi*. Its reference to *Melonechinus multiporus* as a synonym by Miss Klem is certainly wide of the mark.

St. Louis Group, Lower Carboniferous, Hardin County, Kentucky, holotype in University of Chicago Collection 6,623, whence it was kindly loaned me by Professor Stuart Weller.

****Oligoporus halli* sp. nov.**

Plate 47, figs. 11, 12; Plate 48, fig. 5.

Oligoporus sp. Klem, 1904, Plate 1, figs. 3a, 3b.

A large, massive sea-urchin, slightly elliptical in form, with moderately developed melon-like ribs. Height of type 103 mm., diameter through the mid-zone 100 mm., width of ambulacra at the mid-zone 18 mm., width of interambulacra 31 mm.

Ambulacra near the mid-zone with four columns of demi- and occluded plates, the latter slightly the wider, and with scattered isolated plates in the middle line of each half-area. Occluded plates in the middle are curved outward in a low, rounded arch. Pore-pairs in lateral depressions, are situated in the outer portions of each ambulacral plate.

Interambulacra are wide, rounded up from the adradial sutures in a gentle rounded curve. In areas A, C, and I there are eight columns of interambulacral plates at or just above the mid-zone, but in areas E and G there are only seven columns. Areas G and I are not seen in the photographic figure (Plate 48, fig. 5), being on the opposite side of the specimen. In area A (Plate 47, fig. 11) the two ventral rows of plates are restored, as indicated by dotted lines; there are four plates in the third row. The fifth column appears in the sixth row and the sixth column in the eleventh row. The seventh column appears on the left of the center in the fifteenth row. In area C the seventh column appears in the center five rows above the base as far as preserved, and the eighth column originates at or just above the ambitus. The introduction of these two columns in area C is clearly seen in the photographic figure (Plate 48, fig. 5). The apical disc and dorsal portion of the specimen are wanting.

This fine species is known only from the holotype which was kindly loaned me by Mr.

Springer. It is named for the late Professor James Hall, who did such extensive and valuable work for Palaeontology in America. This species is near to *Oligoporus danae*, but differs from it in that it has seven or eight instead of nine columns of plates in an interambulacral area; also in that the interambulacra have a much less accelerated development than in *danae*.

Keokuk Group, Lower Carboniferous, Boonville, Missouri, F. Springer Collection 8,114, originally in G. Hambach's collection.

***Oligoporus danae* (Meek and Worthen).**

Text-figs. 12, p. 54; 237, p. 231; Plate 47, fig. 13; Plate 49, figs. 4, 5; Plate 50, figs. 1-12.

Melonites danae Meek and Worthen, 1860, p. 397.

Oligoporus danae Meek and Worthen, 1860a, p. 472; 1866, pp. 248, 249-251, text-fig. 28, Plate 17, fig. 8;

Lovén, 1874, p. 42; Keyes, 1894, p. 126, Plate 17, figs. 2a, 2b; 1895, p. 182, Plate 20, figs. 2a, 2b;

Jackson, 1896, p. 191, text-fig. 1, p. 193, Plate 6, figs. 30-34; (pars) Klem, 1904, p. 37; Lambert and

Thiéry, 1910, p. 121.

Melonopsis [danae] Meek and Worthen, 1866, p. 249.

Palaechinus danae Meek and Worthen, 1866, p. 251.

Test high, spheroidal, with moderately elevated melon-like ribs in ambulacral and interambulacral areas. Meek and Worthen say of the type that it is too imperfect to give any exact measurements, but it indicates a height of about 4 inches and a breadth of probably from 3.5 to 4 inches. In the large specimen (Plate 49, figs. 4, 5), which is the most nearly complete one known, the ambulacra measure 21 mm. in width at the mid-zone, the interambulacra about 45 mm. in width. The specimen, if complete, would measure about 115 mm. in height, and about 120 mm. in diameter; it is therefore a very large individual.

The ambulacra at the mid-zone are wide, composed of four columns of narrower demi- and wider occluded plates with scattered isolated plates in the middle line of each half-area. The occluded plates in the middle line are arched up as low, rounded, melon-like ribs. Pore-pairs are in shallow valleys on either side, and situated in the outer border of each ambulacral plate. Three or four demi-plates are equal in height to an adradial. Laterally, ambulacral plates bevel over the interambulacrals on the adradial suture. Ventrally, at the peristomal border, there are a few primary ambulacral plates that cross the half-area, and the pore-pairs are uniserial (Plate 50, fig. 8). This is like the character of *Palaeechinus* at the mid-zone, and like *Maccoya* and *Lovenechinus* at the ventral border. Higher up on the right side of area J are two plates which are alternately primary, expanded on the outer border, and occluded, being cut off from interambulacral contact by the enlargement of its fellow. This stage, though very abbreviated, is like the character of *Maccoya* at the mid-zone, and like the second stage in the development of *Lovenechinus*. Higher again, there are four columns of plates, demi- and occluded, but without any isolated plates in the middle of the half-areas. This

stage in *Oligoporus* is like the character of *Lovenechinus* at the mid-zone. Still higher up in this specimen (Plate 50, fig. 9), isolated plates appear in the middle of the half-areas, fixing the character of the type. It will be seen therefore that in *Oligoporus danae* the development of the ambulacrum ventrally passes through a series of stages which are successively comparable to the adult character of the three lower genera of the family as set forth diagrammatically in text-figure 237, p. 231.

The interambulacra are broad, gently curving in elevated ribs, not sharply inclined laterally to the adradial sutures. There are nine columns of plates in each area at or above the mid-zone in all specimens known. Ventrally, there are in the interambulacra (Plate 50, fig. 8) two plates in the basicoronal row, three plates in the second, and four in the third row. In area A the fifth column appears in the fifth row. In a fine specimen shown in Plate 49, figs. 4, 5, there are four interambulacra for study, which is more than is known in any other specimen. In area A (Plate 50, fig. 1) there are nine columns at the mid-zone, and dorsally columns 1 and 2 drop out before reaching the apex, indicating senescence. In area C the ventral portion is restored, as indicated by dotted lines. Assuming that this is correct, the fifth column originates in the sixth row, with a pentagonal plate and a heptagon on its right ventral border. The sixth column originates to the right of the center in the ninth row, with a heptagon on its left ventral border. The seventh column originates in the thirteenth row, with a heptagon on its right ventral border. The eighth column originates in the sixteenth row, with a heptagon on its right ventral border. The ninth column originates to the left of the center with a pentagonal plate in the twenty-first row and with a heptagonal plate on its left ventral border. This is a quite typical area, whereas the following present unusual features. In area E (Plate 50, fig. 2) the ventral portion is also restored, and the adambulacral plates on either side show the beveled sutural faces that extended under the ambulacra when in place. The fifth column originates in the sixth row, with a pentagon on its right ventral border. The sixth column originates in the ninth row, on the left of the center in a pentagonal plate, with a heptagon on its left ventral border, and the seventh column originates in a pentagon in the center, in the twelfth row. In this area two curious anomalies occur just above pentagon 6; in column 3 an aberrant pentagon, P, occurs, and, to compensate for its one side wanting, there is a heptagon on its right side, immediately dorsal to pentagon 6. On the dorsal side of the aberrant pentagon P, lies a heptagon, H. This plate compensates for the one side wanting in pentagon 7, but, instead of lying next to it, is two plates removed. This is a very unusual and rare variant, but emphasizes the mechanical requirements of the case, that, if a side is wanting in one plate, there must be a side added to some other plate in order that all shall be either hexagonal or the equivalent of the same. The eighth column in area E originates in the fifteenth row, on the left of the center, with a pentagon, and a heptagon lies on its right ventral border. Column nine originates in the nineteenth row, but the initial plate, instead of being pentagonal, is

tetragonal, and to compensate for the two sides wanting, there are two heptagons on its right and left ventral borders respectively. Area I (Plate 50, fig. 3; compare Plate 49, fig. 5) is viewed from the interior of the test. The ventral portion is restored. Assuming that this is correct, the fifth column originates in a pentagon in the sixth row, with a heptagon on its left (right as seen from exterior) ventral border. The sixth column originates with a pentagon in the ninth row with a heptagon on its right (left as seen from the exterior) ventral border. Column 7 originates with a pentagon in the twelfth row, and a heptagon is on its right (left as seen from the exterior) ventral border. The eighth column originates with a pentagon in the fifteenth row, with a heptagon on its left (right as seen from the exterior) ventral border. Finally, the ninth column originates in the twenty-third row, and, as in the same column in area E, the initial plate of this column is tetragonal, and to compensate for the two sides wanting, has two heptagonal plates on its right and left ventral borders (pp. 369, 391).

The detailed structure of the interambulacra in the type specimen, and also in a specimen in the Museum of Comparative Zoölogy Collection, 2,997, is figured and discussed in my earlier paper (1896, pp. 193, 197, Plate 6, figs. 31, 34). In both there are nine columns of interambulacral plates, the ninth originating late, considerably above the mid-zone. In this species both ambulacral and interambulacral plates bear numerous small secondary tubercles, with small tapering spines about 5 mm. long. A specimen from Edwardsville, Indiana, in the Museum of Comparative Zoölogy, no. 3,187, shows clearly the ventral developing stages of ambulacral and interambulacral areas, also spines.

A genital plate is high and wide with three genital pores (Plate 50, fig. 6). The outline of this plate presents straight lateral sides for sutural contact with the oculars, so that it may be inferred, although they are not preserved, that the oculars separated the genitals and were insert, as indicated by dotted lines in the sketch. The lantern as shown by two half-pyramids (Plate 50, figs. 11, 12) is inclined, pyramids wide-angled, with moderately deep foramen magnum. The pyramidal suture extends to the base of the foramen as usual, and the dental slides, as seen in internal view, extend to about the level of the foramen. The lateral wing of the pyramids is wide (Plate 50, fig. 11) and has the remains of plicate ridges for the attachment of interpyramidal muscles.

Oligoporus danae is the type species of the genus. The original locality given by Meek and Worthen (1866, p. 251) is Keokuk Group, Lower Carboniferous, Jersey County, Illinois; also Warsaw, Illinois. The type is said to be in the Worthen Collection, now in the University of Illinois at Urbana, Illinois.

Keokuk Group, Lower Carboniferous, Adams County, Illinois, Museum of Comparative Zoölogy Collection 3,142; Warsaw, Illinois, Museum of Comparative Zoölogy Collection 2,997; Keokuk, Iowa, Museum of Comparative Zoölogy Collection 2,998, figured by R. T. Jackson 1896, Plate 6, fig. 30; Salem, Indiana, Museum of Comparative Zoölogy Collection 3,143

3,144 and 3,145; Edwardsville, Floyd County, Indiana, Museum of Comparative Zoölogy Collection 3,187; Missouri, Museum of Comparative Zoölogy Collection 3,146; Washington County, Indiana, F. Braun Collection; Alton, Illinois, Yale University Museum Collection 315, and 316; Felton, St. Louis County, and Curryville, Pike County, Missouri (Keyes).

MELONECHINUS Meek and Worthen.

- Melonites* Norwood and Owen, 1846, p. 225; Meek and Worthen, 1860, p. 396; Lovén, 1874, p. 41; A. Agassiz, 1874, pp. 647, 648, 649; 1881, pp. 78, 80; 1904, p. 80; Duncan, 1889a, p. 15; Jackson and Jaggard, 1896; Jackson, 1896, p. 240; 1899, p. 131 (non *Melonites* Lamarck, 1822, *Animaux sans Vertèbres*, vol. 7, p. 615).
Melonechinus Meek and Worthen, 1860, p. 396; Lambert and Thiéry, 1910, p. 120.
Melechinus Quenstedt, 1875, p. 381.

The test is spheroidal, or exceptionally (*M. obovatus*) obovate, typically more or less strongly marked by elevated melon-like ribs in ambulacral and interambulacral areas, but in two European species the melon-like ribs are wanting. These ribs are due to the thickening of plates, and in most species are slightly, if at all, recognizable in internal molds (pp. 371, 373). In the ambulacra the ribs are formed mainly by the thickening of the two wide median columns of ocluded plates.

Ambulacra are wide, with two columns of wider ocluded plates which extend from the center outward, two columns of narrow demi-plates which extend from the interambulacral sutures inward, and, in addition, at the mid-zone, from one to four irregular columns of isolated plates situated between the demi- and ocluded plates in each half-area. The demi-plates bevel over the interambulacrals on the adradial suture, and may be traced ventrally to the simpler condition at the peristomal border (Plate 56, fig. 3), but otherwise, as seen from the exterior, are practically indistinguishable from isolated plates. From this structure it results that in *Melonechinus* there are at the mid-zone from six to twelve somewhat irregular columns of plates in each ambulacral area, the two halves of an area being equally balanced. In the lower genera of the family the structure of the ambulacra was essentially alike in all species of each genus, but in *Melonechinus* there is much specific difference, and, as the ambulacrum is the most important structural and physiological part, I consider those species with the simplest ambulacra as the lower species, and those with more complex ambulacra as progressively higher species. As stated, the melon-like ridges in the ambulacra are formed mainly by the median thickening of the two central columns of ocluded plates (Plate 60, fig. 3). The pore-pairs are in two more or less deeply depressed valleys on either side. Each pore-pair is surrounded by a peripodium (Plate 61, fig. 8), which, however, is commonly worn away and the pores lie in the outer border of each ambulacral plate. This is the character as seen from the external or distal side (Plate 56, fig. 4). As seen from the proximal, or internal aspect (Plate 56, fig. 5), ocluded plates

are narrower than on the exterior, and demi-plates, opposite horizontal interambulacral sutures are higher and laterally fan-shaped (compare text-fig. 244, p. 338). The pore-pairs on the inner aspect lie near the outer border of the occluded plates as they do on the exterior, but they lie near the inner border of the demi-plates, and in all isolated plates the pore-pairs are approximately in the middle of each plate, instead of near the outer margin of the plate, as they are in all plates on the exterior (Plate 61, figs. 5-9). Ambulacral plates bear small secondary tubercles and spines similar to those of the interambulacra (Plate 61, fig. 8), (pp. 54, 59).

Such being the structure of the ambulacrum at the mid-zone, the ventral developmental characters are of great interest. Near the peristomal border in *Melonechinus* there are typically four columns of ambulacral plates (Plate 56, figs. 2, 3), narrow demi- and wider occluded plates; this is the character of plates at the mid-zone in *Lovenechinus* (Plate 42, fig. 2), and as a third stage in the development of *Oligoporus* (Plate 50, fig. 8). Passing dorsally in *Melonechinus* (Plate 56, fig. 3), soon scattered isolated plates appear in the middle of each half-area; this is like the character at the mid-zone in *Oligoporus* (Plate 50, fig. 7). Again, passing dorsally in *Melonechinus*, the isolated plates become more frequent, so as to come in vertical contact, and thus a new column is attained and the essential generic character acquired. If the species is to have only six columns of plates at the mid-zone, the ventral development goes no further, but in others additional isolated columns appear with dorsal growth until the full complement of the species in hand is attained. From this it follows that species with many columns of isolated plates pass through stages with fewer columns, which stages are directly comparable to the condition at the mid-zone of lower species in the genus, as briefly shown in the diagram (text-fig. 237, p. 231).

While this is the typical character of the development of the ambulacrum in *Melonechinus*, as I have traced it in several species and many specimens, in one specimen of *Melonechinus multiporus* a still simpler condition occurs. In this choice individual (Plate 57, figs. 1, 3; text-fig. 245, p. 382), in area B, ventrally there are a few primary plates, which pass directly across the half-areas, and, while not typical as a ventral developing character in *Melonechinus*, these plates express a reversionary radial variation to the character typical of adult *Palaeochinus*, the lowest genus of the family, and also to a condition that is typical of the ventral border as a developing stage in *Maccoya*, *Lovenechinus*, and *Oligoporus*. And yet some people maintain that the recapitulation theory is a myth, and stages in development do not exist!

While the ventral developing stages are the most clear, yet dorsally the ambulacrum in *Melonechinus* presents a series of localized stages in the young last added plates. Next to the ocular are found few, even as few as two plates (Plate 53, fig. 1; Plate 56, fig. 6), and, when there are two, the condition represents two columns as a stage, which is simpler than the usual ventral stage with four columns and is comparable to the typical condition of *Palaeochinus*. Passing ventrally to the next older plates, we find four columns (Plate 52, fig. 2), comparable

to the typical condition of *Lovenechinus*. Further ventrally, some scattered isolated plates appear (Plate 52, fig. 2), which, as a stage, repeat the typical character of *Oligoporus*. Then the isolated plates become more frequent so that a third column is attained, which brings it to the condition typical of the lowest species in the genus. As one passes ventrally toward the mid-zone, the number of columns increases progressively until that characteristic of the species in hand is attained (Plate 57, fig. 1; text-fig. 245, p. 382; Plate 59, fig. 1). Thus do dorsal localized stages repeat, and in a measure go farther than ventral youthful stages in recapitulating the features characteristic of lower genera in the family or lower species in the genus, as diagrammatically shown in text-fig. 237, p. 231.

In considering the ambulacrum in the *Perischoechinoida*, Mr. Agassiz (1874, pp. 648, 649) makes certain statements to which it seems necessary to call attention. He says (p. 648), "In *Archacocidaris* (Fig. 2) [this figure is *Melonechinus multiporus*] there are four plates in the ambulacra; each plate forming vertical rows, much as in *Hipponoë* and *Holopneustes*." *Archacocidaris* has two columns of simple plates in each ambulacrum (Plate 9, fig. 6), while *Hipponoë* [= *Tripneustes*] and *Holopneustes* both have two columns of compound plates in an ambulacral area, each plate being composed of three elements. In treating of the ambulacrum of *Melonechinus* and other members of the *Perischoechinoida* with many columns of plates in an ambulacral area, Mr. Agassiz (1874, p. 649) compares these with the plates in *Stomopneustes*, *Strongylocentrotus*, and *Heterocentrotus*. I do not think that these are parallel cases because in the *Centrechinoida* there are two columns of compound ambulacral plates in an ambulacral area and the component elements of these compound plates are entirely distinct from the many columns of simple plates that occur in certain Palaeozoic types.

The interambulacra in *Melonechinus* are somewhat wider than the ambulacra or exceptionally (*M. obovatus*) are narrower. Typically, they are gently or sharply rounded up from the adradial sutures in lower or higher melon-like ribs (Plates 51, 55, 60), which are formed mainly by the thickening of the plates. In two European species the melon-like ribs are apparently absent in the interambulacra as they certainly are in the ambulacra. There are from three to eleven columns of plates in an interambulacral area at or above the mid-zone, three (*obovatus*) being the smallest, and eleven (*giganteus*) the greatest number known in the genus and the family. Plates of adradial columns are pentagonal and bevel under the ambulacrals as in other genera of the family, and the plates of median columns are hexagonal or the mechanical equivalent of the same; that is, if one plate has less than six sides, some other plate has more than six to compensate (p. 68). Dorsally, near the apical disc, young interambulacral plates are more or less rhombic (Plate 57, fig. 1; text-fig. 246, p. 382), but with growth, as they are pushed ventrally by later added plates, the ventral and dorsal borders of each plate are soon truncated, and converted into hexagons, by contact with associated plates in their own vertical series. There is no imbrication of interambulacral plates, the sutures, excepting the

adradial, being perpendicular to the surface, but on account of the thickness of the plates the sides are far from parallel, being often almost wedge-shaped in some of the thick-plated species. Interambulacral plates bear small secondary tubercles with corresponding small spines as in the ambulacra.

In the lower genera of the family the species are largely based on the number of interambulacral columns in an area; but in *Melonechinus* there is a large range in the number of ambulacral columns, and this is considered a more important character, taking precedence over the number of interambulacral columns, which is relegated to a secondary place as a species differential. It is worth noting that the highest species, *M. giganteus*, has the highest number of interambulacral columns known in the family (Plate 60, fig. 3; Plate 61, fig. 8).

The interambulacra of *Melonechinus* ventrally have two plates in the basicoronal row (discussion, p. 66), and three plates in the second row (Plate 56, fig. 2). With rare exception the fourth column originates in the third row, above which additional columns, if added, come in with considerable regularity and with a perfectly definite system, as first shown by Jackson and Jaggard (1896). This system is the same as in all this family, and is shown in a representative species in Plate 57, fig. 1 and text-fig. 246, p. 382 (p. 70).

Mr. Agassiz (1881, pp. 78, 79, 95) considers that the numerous interambulacral plates of *Melonechinus* and other genera of the Perischoechinoida are derived from the splitting up of primary interambulacral plates, but I cannot agree with this view (pp. 28, 64, 378). Mr. Agassiz (1881, p. 79) also considers that the large number of coronal plates in the Palaeoecchinidae is a feature in which they "show most unmistakably their systematic affinity to the Crinoids." In thus expressing himself he supports the view that he earlier published (1864, p. 16), in which he considered the genera of the Perischoechinoida as "only synthetic and prophetic Crinoids." These statements are in striking contrast to what Mr. Agassiz says in the Revision (1874, p. 645), where he gives structural grounds for widely separating the Perischoechinoida and the Crinoidea. I give reasons (p. 200) for rejecting any close affiliation of the Echini with the crinoids.

The peristome of *Melonechinus* is known in only one specimen (Plate 56, figs. 7, 8), but in this there are many rows of ambulacral plates. In each radial area there are two relatively larger primordial ambulacral plates adorally, and, passing aborally, the number of plates increases to many plates in a row on the outer border of each ambulacral area of the peristome. Three non-ambulacral plates occur interradially in probably each area. This is the only case of a peristome known in the family (pp. 80, 378).

The apical disc in *Melonechinus* is small measuring proportionately about 13 to 25 % of the diameter of the test. It is interesting to note that in *Melonechinus springeri* which is a primitive species in the genus, the apical disc is relatively large; its diameter being about 23 % of the diameter of the test; whereas in *M. liratus* and *M. multiporus* which are more specialized

species in the genus, the apical disc is relatively smaller, its diameter being about 13 to 16 % of the diameter of the test (pp. 87, 104, 339). The apical disc is composed of five oculars and five genitals. The oculars separate the genitals, reaching the periproct, are imperforate, and ventrally cover the ambulacra and laterally the interambulacra in part on either side. No exceptions to these statements are known to me in the genus (Plate 56, fig. 6). The genitals are high and wide, presenting one face to the periproct, one to each ocular on either side, and ventrally a rounded face to the interambulacrum, without reaching the ambulacra on either side (Plate 53, fig. 1; Plate 56, fig. 1). It is often difficult to see the interambulacral plates extending quite to the oculars, but, barring something abnormal, I believe this is the character (p. 89). Genital plates in this genus have typically three or four pores each. Occasionally only two, or one, or even no pores are visible (p. 149). When one or none are visible, it is doubtless a case of obliteration of pores in fossilization. I have seen no case of madreporic pores in the genus, though such are figured by Keyes (1894) in *M. multiporus*. His observation is further considered under that species. The plates of the periproct strangely enough are known in only one specimen, an external mold (Plate 56, fig. 1). They are small, angular, and evidently fill the area as in *Palaeochinus* and *Maccoya*. The lantern is inclined, pyramids wide-angled, with moderately deep foramen magnum, and the teeth extend a considerable distance beyond the pyramids ventrally.

Mr. Agassiz (1892, pp. 72, 73) expresses the view that "the many pores found on the genital and ocular plates of the Palaeochinidae" are "only perforated tubercles, or the pits left after the minute radioles have been broken off." This family does not have perforate tubercles on any part of the test, and the pores pass directly through the genital plates, as the perforations of tubercles do not. I believe no one has shown supernumerary pores in ocular plates in this family excepting Baily, and he was mistaken (p. 309). I have never seen any pores perforating ocular plates in the Palaeochinidae. Mr. Agassiz (1881, p. 12) says that many genital plates may be occupied by the madreporite in the Palaeochinidae as shown in several genera figured by Baily, Worthen, and others. I know of no case in the Palaeochinidae in which a madreporite has been previously figured excepting by Keyes in *Melonechinus*, and I know of no case in this or any other family of Palaeozoic Echini in which madreporic pores have been shown in more than one genital plate (p. 172).

Considering the lantern of *Melonechinus multiporus* as figured by Meek and Worthen (1866), Mr. Agassiz (1874, p. 647) says that there is a furrow in the center of the teeth, resembling that of the teeth of *Archaeocidaris* as figured by Müller (1857) (my Plate 10, figs. 6, 7). Neither Meek and Worthen nor Müller as far as I am aware figured teeth, but they did figure dental pyramids, and the "furrow" referred to by Mr. Agassiz is evidently the median suture of the pyramids. *Melonechinus* does not have a furrow on the exterior of the teeth though doubtless there was a groove on the inner side as in other members of the *Perischoechinoida* (text-figs. 207, 208, p. 184).

Melonechinus occurs in the Lower Carboniferous of America, Great Britain, and Russia. The type species is *Melonechinus multiporus* (Norwood and Owen).

*Key to the Species of Melonechinus.*¹

- Six columns of ambulacral and four columns of interambulacral plates in each area *M. dispar* (Fischer von Waldheim), p. 365.
- Six columns of ambulacral plates, and at the mid-zone five columns of interambulacral plates, a sixth column coming in dorsally in each area *M. parrus* (Hambach), p. 365.
- Six columns of ambulacral plates, and six columns of interambulacral plates at or just above the mid-zone, with a strong tendency to adding a seventh column dorsally in each area *M. springeri* sp. nov., p. 366.
- Eight columns of ambulacral and six columns of interambulacral plates in each area, melon-like ribs low, gently rounded *M. crassus* (Hambach), p. 367.
- Eight columns of ambulacral and six columns of interambulacral plates; a seventh interambulacral column may appear dorsally, or exceptionally, even an eighth column in each area; melon-like ribs high, sharply elevated *M. indianensis* (Miller and Gurley), p. 369.
- Eight columns of ambulacral plates and seven (or in one area of the type, six) columns of interambulacral plates in each area. Melon-like ribs strongly and sharply elevated *M. stewartii* (Safford), p. 371.
- Eight columns of ambulacral and seven columns of interambulacral plates at the mid-zone in each area; test small *M. septenarius* (Jackson), p. 373.
- Ten columns of ambulacral and three columns of interambulacral plates in each area; test obovate *M. obovatus* sp. nov., p. 373.
- Ten columns of ambulacral and eight columns of interambulacral plates in each area; high, steeply rounded, melon-like ribs in ambulacral and interambulacral areas *M. liratus* sp. nov., p. 374.
- Ten columns of ambulacral and dorsally eight or nine columns of interambulacral plates (rarely seven columns only in an area) in each area; low, rounded, melon-like ribs in ambulacral and interambulacral areas *M. multiporus* (Norwood and Owen), p. 375.
- Twelve columns of ambulacral and six columns of interambulacral plates in each area; melon-like ribs wanting *M. keepingi* sp. nov., p. 384.
- Twelve columns of ambulacral and seven columns (possibly more) of interambulacral plates in each area; melon-like ribs wanting *M. etheridgii* (Keeping), p. 385.
- Twelve columns of ambulacral and nine columns of interambulacral plates in each area; melon-like ribs strongly developed *M. vanderbilti* sp. nov., p. 388.
- Twelve columns of ambulacral and eleven columns of interambulacral plates in each area; melon-like ribs strongly developed *M. giganteus* (Jackson), p. 389.

¹ *Melonites* (= *Melonechinus*) *youngi*, of which no description has been published, is considered under *Nomina Nuda*, p. 457.

Melonechinus dispar (Fischer von Waldheim).

Plate 51, figs. 1-3.

Palechinus dispar Fischer von Waldheim, 1848, p. 243, Plate 3, figs. 4a-4d (on the plate there are only three figures; all copied here).

Palechtinus dispar (by typographical error) Fischer von Waldheim, 1848, p. 247.

Palaeocchinus dispar Eichwald, 1860, p. 651.

Melonites dispar Lovén, 1874, p. 42; Jackson, 1896, p. 240; Klem, 1904, p. 41.

Melonechinus dispar Lambert and Thiéry, 1910, p. 120.

The test is spheroidal, with moderately elevated melon-like ribs. Ambulacra broad, with six columns of plates at the mid-zone; according to the figures the ambulacral plates are more regular in form and size than in other known species of the genus. In the interambulacra there are four columns of quite high hexagonal and pentagonal plates, which, as figured, bear few small widely spaced secondary tubercles.

This species has as few columns of ambulacral plates as any in the genus, and also the least number possible to be included in this genus. It has the least number of interambulacral plates of any species with six columns of ambulacral plates, and therefore it is considered the most primitive species in the genus.

Lower Carboniferous Limestone, Ratofka, Russia, the locality of the type; Carboniferous, "Étage moyen," Moscow, and in Lower Carboniferous of the village of Sloboda, in the Government of Toula, Russia (Eichwald).

***Melonechinus parvus** (Hambach).

Plate 51, fig. 4; Plate 52, fig. 1.

Oligoporus parvus Hambach, 1884, p. 550, Plate C, fig. 3; Keyes, 1894, p. 127; 1895, p. 183; Klem, 1904, p. 40; Lambert and Thiéry, 1910, p. 121.

The test is small, spheroidal, and much compressed in the type specimen. Diameter through B, G, 55 mm. This is doubtless somewhat exaggerated by the vertical compression of the test. Width of ambulacrum B, at the mid-zone, 15 mm.; width of interambulacrum A about 20 mm.

Ambulacra are wide, with six columns of plates at the mid-zone, one column of wide ocluded plates, one of demi-, and one quite irregular column of isolated plates in the middle line of each half-ambulacrum. This character removes the species from *Oligoporus* in which it was described by Hambach, and places it as one of the lowest species of *Melonechinus*.

In the development of the ambulacrum (Plate 52, fig. 1), there are ventrally in area B four columns of plates, narrow demi- and wide ocluded. Above this *Melonechinus* stage,

scattered isolated plates appear, the Oligoporus stage; then the isolated plates become sufficiently frequent to form a column when the species character in this respect is attained.

The interambulacra have five columns of plates at the mid-zone in areas A and C, the two which are most nearly complete. In area A, in addition, a sixth column is represented dorsally by a single plate, dorsal to which the test is wanting (Plate 52, fig. 1). In this area the first two rows are restored as indicated by dotted lines. The fourth column originates in the third row, the fifth column in the eighth row, and the sixth column in the sixteenth row, with a pentagon and ventrally situated heptagon as usual. Area C is only partially preserved. The fifth column comes in at about the same zone as in area A. In column 4 there is an aberrant pentagon X, and, to compensate for its one side short, an adjacent adradial plate has taken on an additional side. Interambulacral plates bear small secondary tubercles, with small spines.

Lower St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. The type specimen is in Mr. Frank Springer's collection 8,118, and was from Professor Hambach's collection. Miss Klem also gives Hardin County, Kentucky, as a locality for the species.

****Melonechinus springeri* sp. nov.**

Text-figs. 19, p. 59; 237, p. 231; Plate 51, fig. 5; Plate 52, figs. 2-6.

The test is small, high, and spheroidal, with strongly developed melon-like ribs in ambulacral and interambulacral areas. Known from a single specimen in Mr. Springer's collection. Height 28 mm., diameter through the mid-zone about 32 mm. The actual measurements in diameter are: through B, G, 30 mm.; C, H, 32 mm.; and J, E, 35 mm. Width of an ambulacrum at the mid-zone 8 mm.; width of an interambulacrum 11 mm.

Ambulacra are wide with, at the mid-zone, six columns of plates in each area, composed of wide occluded, narrow demi-, and one irregular column of isolated plates in the middle line of each half-area (Plate 52, fig. 2). The occluded plates are medially elevated in a high, arching, melon-like ridge. Ventrally in the ambulacra, as developing stages, there are two columns in each half-area (Plate 52, fig. 3) of wide occluded, and narrow demi-plates; higher up scattered isolated plates appear, which, higher again, become more frequent and fall into a vertical columnar series, the species character. Dorsally, near the ocular, as localized stages (Plate 52, fig. 2), there is a single column of ambulacral plates in each half-area. Passing ventrally, next we find two columns in each half-area, then two columns with, in addition, scattered isolated plates, which soon become so frequent as to make a continuous column, the species character. It is interesting to see in this primitive species of the genus how complete the ventral developing and dorsal localized stages are, and how closely they can be compared with the lower genera in the family (text-fig. 237, p. 231). The dorsal localized stages are more complete in this than in some of the higher species of the genus, in which some stages are more or less obliterated by acceleration of development.

The interambulacra are a little wider than the ambulacra, arching from the adradial sutures outward in relatively high melon-like curves. In each area there are six columns of plates at or a little above the mid-zone. In areas E, G, and I there are only six columns, but in A and C a seventh column is represented by a few plates dorsally in the middle line of each area (Plate 52, fig. 2). Interambulacral and ambulacral plates alike bear small secondary tubercles with corresponding small spines about 3 mm. long. Ventrally, in Plate 52, fig. 4, the first three rows of interambulacral plates are restored, as indicated by dotted lines. Assuming that these are correct, the fifth column originates in a pentagonal plate in the seventh row, with a heptagon on its left ventral border. The sixth column originates in the eleventh row with a pentagon, on the right of the center, and bearing a heptagon on its left ventral border. Dorsally, the adradial columns 1 and 2 drop out before reaching the apical disc, indicating senescence. The apical disc is imperfectly preserved, but the diameter as closely as it can be ascertained is about 7.5 mm., which is proportionately about 23 % of the diameter of the test. This is proportionately larger than in more specialized species as *M. multiporus* and *M. liratus* in which the diameter of the apical disc is only 13 to 16 % of the diameter of the test. An ocular plate in place covers the ambulacrum and laterally in part the interambulacra on either side. Two genital plates lie against the ocular, one twisted out of place and in part covering the ocular. Genital pores are not shown.

This species is one of the smallest known in the genus, yet the type represents an adult, or even old-age individual, as indicated by the dropping out of adambulacral columns dorsally. As regards the ambulacrum, it is one of the simplest species known in the genus, but in its interambulacral structure is more specialized than the two previously described species. I take pleasure in naming this species for Mr. Frank Springer, the eminent crinoid specialist, who generously loaned me his whole collection of Palaeozoic Echini, which has been an invaluable aid in my work.

St. Louis Group, Lower Carboniferous, Elizabethtown, Kentucky, F. Springer Collection 8,103.

****Melonechinus crassus* (Hambach).**

Plate 51, fig. 6; Plate 52, figs. 7-11.

Melonites crassus Hambach, 1884, p. 548, Plate C, fig. 1; Keyes, 1894, p. 126; 1895, p. 182; Jackson and Jaggard, 1896, p. 137; Jackson, 1896, p. 240; Klem, 1904, pp. 8, 41, Plate 1, figs. 2a-2d.
Melonechinus crassus Lambert and Thiéry, 1910, p. 120.

The test of this fine species is high and spheroidal, with strong, rounded, melon-like ribs in ambulacral and interambulacral areas. Known only from the type specimen (Plate 51, fig. 6), which is compressed and with a dorso-ventral thrust. Height of the test about 90 mm., diameter about 111 mm., but this measurement is somewhat exaggerated by lateral compres-

sion; width of the ambulacrum at the mid-zone, 24 mm.; width of the interambulacrum at the same zone, about 26 mm.

Ambulacra are wide, nearly equaling the width of the interambulacra, with eight columns of plates at the mid-zone composed of a column of wide ocluded, narrow demi-, and two columns of somewhat irregular isolated plates in each half-area (Plate 52, fig. 7). Hambach says that there are ten columns of ambulacral plates in this species. As I count the plates there are eight columns, but in the irregular character of the ambulacra in *Melonechinus*, where there are many plates, it is easy to count two more or two fewer columns in an area, according as one includes or eliminates irregularities. The pore-pairs are in peripodia and lie on the outer portion of each ambulacral plate. Small secondary tubercles and spines about 3 mm. long occur on the ambulacral areas (Plate 52, fig. 10). The spines of these areas are perhaps a trifle longer than spines on the interambulacral plates (Plate 52, fig. 11); but they certainly are not twice as long as stated by Hambach and also by Miss Klem. In all species of this family the spines of both areas are essentially alike, as far as known, and this species is probably no exception to the rule. The slight differences observed may well be ascribed to conditions of preservation. The ambulacrum ventrally has two columns of ocluded and two of demi-plates (Plate 52, fig. 9), but scattered isolated plates soon come in in the middle line of each half-area and represent the second stage in development.

The interambulacra are a trifle wider than the ambulacra. At the mid-zone there are six columns of plates in areas A, C, E, and G, but area I is imperfect, so that the number dorsally could not be ascertained. Hambach says that there are five columns, but he apparently overlooked an adambulacral column which in area C, one of the best areas, is sunken deeply in the lateral furrow, and is in part wanting in this area. Interambulacral plates bear numerous small secondary tubercles and spines, which, as preserved, are not quite so long as those in the ambulacral areas (Plate 52, fig. 11). In area E the ventral portion is quite complete, but the plates of the basicoronal row are restored (Plate 52, fig. 8). There are three plates in the second row, four in the third, and the fifth column comes in in the seventh row. In area C (Plate 52, fig. 7) the fifth column originates in a pentagon, in the middle of the area, with a heptagon on its left ventral border. Three rows higher up and well below the mid-zone the sixth column originates with a pentagonal plate on the left of the center and with a heptagon on its right ventral border. The specimen (Plate 51, fig. 6) is oriented by the introduction of columns and ventral structure, and is reversed from the orientation given by Professor Hambach. Dorsally the apical system is wanting.

Lower St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. The holotype and only known specimen is in Mr. Frank Springer's collection 8,116, and was from Professor Hambach's collection.

****Melonechinus indianensis*** (Miller and Gurley).

Text-fig. 237, p. 231; Plate 51, figs. 7-9; Plate 53, figs. 1-4.

Melonites indianensis Miller and Gurley, 1894, p. 5, Plate 1, fig. 1; Jackson, 1896, p. 240.

Melonites multiporus (pars) Klem, 1904, p. 43.

Melonechinus indianensis Lambert and Thiéry, 1910, p. 121.

A relatively small species, the type being the largest known individual. Test spheroidal, with sharply elevated melon-like ribs in ambulaeral and interambulaeral areas. The holotype (Plate 51, fig. 7) measures 54 mm. in height, 67 mm. in diameter at the mid-zone through the axis J, E; width of the ambulaera at the mid-zone 16 mm., width of the interambulaera 21 mm.

The ambulaera are wide, at the mid-zone with eight columns of plates composed of wide ocluded, narrow demi-, and two irregular columns of isolated plates in each half-area (Plate 53, fig. 3). The ocluded plates medially are arched up in a high, rounded, melon-like ridge. Pore-pairs are in deep valleys on either side of the ambulaeral areas, each pair in a well marked peripodium, situated in the lateral portion of each plate. In the developing area ventrally (Plate 53, fig. 2) there are near the peristomal border two columns of plates, narrow demi- and wide ocluded in a half-area. Higher up, as shown, isolated plates appear in the middle line of the half-areas as a second stage, then isolated plates become continuous so as to form one column, repeating in this stage the character of species like *springeri* that typically have only one isolated column. Then a second isolated column appears, fixing the species character in this feature. Dorsally, as localized stages in development, near the apical disc (Plate 53, fig. 1) there is a single column of primary plates in each half-area. Ventrally, they pass quickly into stages of two columns, then three, and finally four in a half-area. These ventral and dorsal stages and their relations to lower genera and species are set forth diagrammatically in text-fig. 237, p. 231. The dorsal localized development of *indianensis* is more accelerated than in the lower species, *springeri*, as in that region the Oligoporus stage of scattered isolated plates is skipped in *indianensis* although ventrally this character is retained as a developing stage.

The interambulaera of *indianensis* are slightly wider than the ambulaera, and are rounded up in high, wide, melon-like ridges which laterally dip suddenly down to the adradial sutures. In the type there are six columns of plates in four interambulaeral areas, A, C, E, and G, but in area I (Plate 53, fig. 4), as an exception, there are seven columns and even an eighth is represented by two plates. This is evidently a progressive variation, not common in the species, since in two other specimens here figured all the areas have six columns only. In this unusual area (Plate 53, fig. 4) the basicoronal row and a few plates on either side are restored as indicated by dotted lines. There are three plates in the second row, and four in the third. The fifth column originates in the middle in the seventh row with a tetragonal plate, which is very

exceptional (compare tetragonal plate of ninth column in Plate 50, figs. 2, 3, and Plate 59, fig. 14; pp. 358, 391). To compensate for the two sides wanting there are two heptagonal plates, H, one on its left and one on its right ventral border. The sixth column originates on the left of the center in the tenth row, with a pentagonal plate which has a heptagon on its left ventral border. The seventh column originates in the fourteenth row in the middle of the area with a heptagon on its right ventral border. The eighth column, consisting of only two plates, originates in the eighteenth row. Both plates of this column are pentagons, and a heptagonal plate lies on the ventral border of one and the dorsal border of the second pentagon, compensating for the one side lacking in each. Dorsally, in this specimen (Plate 53, fig. 1) the adambulacral columns 1 and 2 drop out before reaching the apical disc, so that dorsally columns 3 and 4 assume an adradial position. In addition, one other column has dropped out in several areas. In area C column 4 drops out so that column 6 assumes an adradial position adapically; in area E, column 5 drops out, and in area G, column 6 drops out, before reaching the apical disc.

In the type the apical disc is in place and complete; it measures proportionately 16 % of the diameter of the test. The five oculars all reach the periproct, are imperforate, and ventrally cover the ambulacra and laterally the interambulacra in part on either side. The genitals are high and wide, bounded by the periproct dorsally, the oculars laterally, and ventrally, in a long curving line, by the interambulacra, which laterally extend in a narrow, wedge-like fashion to their points of ocular contact. There are three pores in genital G, in other plates no pores or fewer than three; they have doubtless been obliterated in the process of silicification (p. 363).

A small specimen in Mr. Braun's collection from Greenville, Indiana (Plate 51, fig. 8) is completely silicified and preserved without distortion. There are eight columns of ambulacral plates and six columns of interambulacral plates respectively in each area. The angles of the melon-like ribs are exceptionally sharp and well preserved. The apical disc measures proportionately 18 % of the diameter of the test.

A specimen in the Museum of Comparative Zoölogy Collection 3,147, from Allen County, Kentucky (Plate 51, fig. 9), is silicified, and stained a yellow amber color; much wear has rounded the outlines. It has the eight columns of ambulacral plates, and in each interambulacrum six columns of plates, the species character. Another specimen in the Museum of Comparative Zoölogy Collection 3,081, from the Lower Carboniferous, Berea, Kentucky, is of much interest as a silicified internal mold, and is the best internal mold of any specimen of the genus known to me. The specimen although partially wanting is perfect in form and free from all distortion. It measures 40 mm. in height and 50 mm. in diameter. At the mid-zone the ambulacra measure 12 mm. in width, and the interambulacra 27.5 mm. in width. These proportions differ considerably from those given for external measurements in the type, but

this is in part due to the fact that ambulacral plates bevel over the adambulacrals on the adradial suture so that ambulacra on the interior are necessarily narrower than on the exterior. There are eight columns of plates at the mid-zone in the ambulacral areas, but only two plates dorsally where the ambulacra are in contact with the oculars. In the interambulacra there are six columns of plates at the mid-zone in the areas as far as preserved, but in four interambulacra a seventh column appears dorsally. In the ambulaerium, the demi-plates opposite horizontal interambulacral sutures are high and laterally fan-shaped, as in Plate 56, fig. 5, also as in that figure, the pore-pairs are on the outer portion of occluded plates, the inner portion of demi-plates, and in the middle of isolated plates. The impression of the apical disc is very clearly preserved and measures 11.5 mm. in diameter, which is proportionately 23 % of the diameter of the test. This is proportionately larger than apical discs of other specimens as measured from the exterior of the test; but this is in part due to the fact that genital plates probably present a bevel on their adoral face as in Plate 50, fig. 6, so that a measurement taken from the interior would naturally be somewhat larger than one taken from the exterior. The periproctal area measures 5.5 mm. in diameter. Impressions of all the oculars and genitals are in place. The oculars all meet the periproct and adorally cover the ambulacra and laterally the interambulacra in part on either side. Melon-like ribs are quite pronounced in this internal mold both in ambulacral and interambulacral areas. This character differs from internal molds in other species in the genus and family that I have seen. The melon-ribs are formed mainly by the thickening of the plates and internal views usually show little or nothing of this character, as seen in Plate 38, fig. 9, and Plate 54, figs. 2, 3 (p. 359).

The holotype is from the St. Louis Group, Lower Carboniferous, Greenville, Harrison County, Indiana; it is in the Chicago University Collection 6,622, whence it was kindly loaned me by Professor Stuart Weller. Same horizon and locality, F. Braun Collection. Lower Carboniferous, Allen County, Kentucky, Museum of Comparative Zoölogy Collection 3,147; Lower Carboniferous, Berea, Kentucky, Museum of Comparative Zoölogy Collection 3,081; Lower Carboniferous, Jackson County, Missouri, Museum of Comparative Zoölogy Collection 3,148 (all from R. T. J. Coll.).

****Melonechinus stewartii* (Safford).**

Plate 53, figs. 6-8; Plate 54, fig. 1; Plate 56, fig. 1.

Melonites stewartii Safford, 1869, p. 346, Plate 6 (1), figs. 1a-1d.

Melonites multipora (pars) Keyes, 1895, p. 181.

Melonites multiporus (pars) Klem, 1904, p. 42.

This specimen is represented by a very perfect external calcareous mold of the dorsal half of the test from about the mid-zone up. So perfect is it that not only outlines of plates, but spines, tubercles, and peripodia can be clearly made out. It is known only from Safford's

original type specimen which is in the Vanderbilt University Collection, and was kindly loaned me by Professor L. C. Glenn of that institution.

As gathered from the dorsal half, the test is high and spheroidal, with strongly and sharply elevated melon-like ribs in ambulaeral and interambulaeral areas. These are shown in the plaster cast of the type (Plate 54, fig. 1). Diameter 77 mm., width of the ambulaera near the mid-zone about 23 mm., width of the interambulaera in the same plane about 24 mm.

The ambulaera are of about the same width as the interambulaera near the mid-zone, with eight columns of plates, wide ocluded, narrow demi-, and two irregular columns of isolated plates in each half-area (Plate 53, fig. 6). The ocluded plates medially are elevated in a high, steeply rounded, melon-like curve. Pore-pairs are in peripodia, situated in the outer portion of each ambulaeral plate. The figure of ambulaeral detail is drawn directly from the original mold, therefore the orientation is reversed from what it would be if seen from the exterior. The interambulaera are elevated, in high, rounded, melon-like ribs, which laterally dip down steeply to the adradial sutures. In four areas there are seven columns of interambulaeral plates at or above the mid-zone, but in area I there are only six columns. In areas E and G the seventh column originates above the lower border, as preserved, with a pentagonal plate bearing a heptagonal plate on the right ventral border (Plate 53, fig. 8). This figure is also drawn directly from the original external mold, therefore the orientation is reversed from what it would be if seen from the exterior. Ambulacral and interambulaeral plates bear small secondary tubercles, and spines about 3 mm. long.

Dorsally, the apical disc is in place, and it measures proportionately about 17% of the diameter of the test (Plate 56, fig. 1, was drawn from a wax cast of the original mold). There are low, small, imperforate oculars all reaching the periproct, and five wide, high genitals. Genital I has three pores situated as usual toward the ventral border of the plate. In the other genitals the impressions of pores are somewhat scattered and doubtful as to the number of pores in each plate. In this specimen impressions of periproctal plates are in place. They are small, angular, and evidently fill the area, as in *Maceoya* and *Palaeochinus* where these plates are better known. In all cases these plates are closely similar to those of a Recent *Eueidaris* (text-fig. 66, p. 98). This is the only specimen of the genus *Melonechinus* in which the periproctal plates are known.

This species is close to *multiplus*, but differs from it in that the melon-like ribs are much higher and more sharply rounded (compare Plate 55), and the ambulacral areas are proportionately somewhat wider. There are eight columns of ambulacral plates in *stewartii* whereas there are usually ten columns in *multiplus*; also there are seven or six columns of interambulaeral plates in each area in *stewartii*, whereas in *multiplus* there are typically eight or nine columns, very rarely seven, and as few as six are unknown.

Professor Safford says of this fossil that the precise locality is not known to him, but that

it is from Middle Tennessee, and he had reason to think from the Lithostroton bed which belongs to the St. Louis Group of the Lower Carboniferous. The holotype is in Vanderbilt University Collection, Nashville, Tennessee, 223. Casts of this specimen are in F. Braun's collection; and in the Museum of Comparative Zoölogy Collection 3,150.

****Melonechinus septenarius* (Jackson).**

Plate 51, fig. 10; Plate 53, fig. 5.

Melonites septenarius Jackson, 1896, p. 182, Plate 9, fig. 49; Klem, 1904, p. 43.

Melonechinus septenarius Lambert and Thiéry, 1910, p. 121.

The test is small and spheroidal. The type and only known specimen is an internal siliceous mold, so that the external characters, including melon-like ribs, are unknown. Width of the ambulacrum at the mid-zone about 13 mm., width of the interambulacrum 23 mm.

The ambulacrum at the mid-zone has eight columns of plates. As the plates are internal impressions, the pore-pairs are near the outer border of occluded plates, the inner border of demi-plates, and about the middle of isolated plates (compare Plate 56, fig. 5). About three demi-plates equal the height of an adradial plate. There are seven columns of interambulacral plates in an area. The seventh column is peculiar in that it originates far to the right of the center, but has as usual a heptagonal plate on its left ventral border. Near the mid-zone an adventitious pentagon, P, occurs, and next to it on the right is a heptagon, A, the extra side of which compensates for the missing side of the pentagon.

This species is imperfectly known. It is structurally nearest to *M. indianensis*, but differs in that the ambulacra are proportionately much wider and the seventh column, which is exceptional and late in development in *indianensis*, appears very early in *septenarius*.

Warsaw Limestone, Lower Carboniferous, Buzzard's Roost, Franklin County, Alabama. Holotype in the American Museum of Natural History Collection $\frac{7517}{1}$.

****Melonechinus obovatus* sp. nov.**

Plate 53, figs. 9, 10; Plate 54, figs. 2, 3.

This species is a remarkable type in its character, but is only known from one specimen, which is an internal yellowish calcite mold, so that external characters, including the melon-like ribs, are unknown. Test slightly higher than wide, obovate, and apparently in its original shape without distortion. As the specimen is an internal mold, its horizontal outline presents a continuous curve of one arc (Plate 54, fig. 3), there being no indication of the melon-like ribs which doubtless existed on the exterior. As these ribs are formed mainly by the thickening of the plates, their outline is usually not indicated on the interior of the test (compare Plate 38, fig. 9; pp. 359, 371). Height about 43 mm., diameter through the ambitus 42 mm.; this measurement exceeds the diameter through the mid-zone, as this is one of the very rare cases in which the ambitus, or greatest circumference, is dorsal to the middle of the test (p. 32).

The circumference at the ambitus is 130 mm., width of the ambulaera at the mid-zone 18 mm., width of the interambulaera 9 mm.

The ambulaera are remarkable for the genus in being about twice the width of the interambulaera. At the mid-zone there are ten columns of ambulaeral plates in an area, composed of wide ocluded, narrow demi-, and three irregular columns of isolated plates in each half-area (Plate 53, fig. 9). As the plates are an internal view, the pore-pairs lie in the inner border of the demi-plates and near the middle of isolated plates; also demi-plates opposite horizontal ambulaeral sutures are higher and laterally fan-shaped (compare Plate 56, fig. 5).

The interambulaera at the mid-zone and throughout the areas, as far as they could be ascertained, consist of three columns of plates. This is the only species in the family that has so few columns in an area, and the only other Palaeozoic Echini with three interambulaeral columns in an area are *Lepidesthes wortheni* Jackson and *Meekechinus elegans* sp. nov. (Plate 67, fig. 8; Plate 76, fig. 1). The three columns continue to the apical disc and laterally are in contact with the oculars as usual (Plate 53, fig. 10), (p. 444).

The impress of the apical disc is in place dorsally (Plate 53, fig. 10). It measures 10.5 mm. in diameter, which proportionately is 25 % of the diameter of the test. This is relatively the largest apical disc seen in the genus, and is exceptionally large for the Palaeozoic (pp. 87, 104). It is to be remembered, however, that the specimen is an internal mold, and on the exterior the diameter of the apical disc would doubtless be smaller (p. 362, 371). The oculars all meet the periproct and ventrally cover the ambulaera and laterally the interambulaera in part on either side. The genitals are high and wide, as usual in the genus, but the pores could not be ascertained.

This species has the same number of columns of ambulaeral plates as the two following, but differs from them radically in the number of columns of interambulaeral plates and in the form of the test. It is striking that this species with so highly evolved an ambulaeral structure should at the same time have the least evolved interambulaera known in the family.

Lower Carboniferous, White Creek, Davidson County, Tennessee; holotype in Vanderbilt University Collection, from which it was kindly loaned me by Professor L. C. Glenn.

****Melonechinus liratus* sp. nov.**

Plate 53, fig. 11; Plate 54, fig. 4.

Test high and spheroidal, with strongly and sharply elevated melon-like ribs in ambulaeral and interambulaeral areas. This species is known only from the holotype, which was kindly loaned me for study by Professor L. C. Glenn. Height about 91 mm., diameter about 116 mm., width of the ambulaera at the mid-zone about 36 mm., width of the interambulaera at the same plane 40 mm.

Ambulaera are nearly as wide as the interambulaera at the mid-zone with ten columns

of plates composed of wide occluded, narrow demi-, and three somewhat irregular columns of isolated plates in each half-area. The occluded plates medially are elevated in high, steeply rounded, melon-like ridges. Pore-pairs are in deep sunken valleys on either side and are situated in the outer portion of each ambulacral plate.

The interambulacra are slightly wider than the ambulacra, and are arched up in high melon-like ridges, the outer faces on a gentle curve, laterally dipping suddenly down to the adradial sutures. Each of the three interambulacral areas preserved has eight columns of plates at the mid-zone. Dorsally, the apical disc is partially preserved (Plate 44, fig. 4); it measures 15.5 mm. in diameter, which is about 13 % of the diameter of the test. Ocular D is in place, reaches the periproct, and ventrally covers the ambulacrum and laterally the interambulacra in part on either side. Spaces exist between the genitals for oculars B and J. Four genitals are in place; they are high and wide as usual, each having three genital pores.

This species is close to *multiporus*, having the same number of columns of ambulacral and interambulacral plates as that species has. It differs in the high, steeply rounded melon-like ridges and deeply sunken poriferous areas (compare Plate 55, figs. 1-3; Plate 60, figs. 1, 2).

Lower Carboniferous, detailed horizon and locality unknown, but doubtless, from the lithological character, from Kentucky or Tennessee. Holotype in Vanderbilt University Collection, Nashville, Tennessee, 221.

****Melonechinus multiporus* (Norwood and Owen).**

Text-figs. 13, p. 54; 20, p. 59; 25, p. 70; 48, p. 80; 163, p. 149; 237, p. 231; 245, 246, p. 382; Plate 54, fig. 5; Plate 55, figs. 1-3; Plate 56, figs. 2-13; Plate 57, figs. 1-3; Plate 60, figs. 1, 2; Plate 72, fig. 12.

Melonites multipora Norwood and Owen, 1846, p. 225, text-figs. 1-3; Engelmann, 1847, p. 124; Desor, 1858, p. 159; Roemer, 1855, p. 312, Plate 12, figs. 1-6e; Meek and Worthen, 1866, p. 227, text-fig. 21; p. 228, text-figs. 21, 22; p. 248, text-fig. 27; A. Agassiz, 1874, pp. 647, 648, text-figs. 1, 2, 5, 6; Quenstedt, 1875, p. 380, Plate 75, figs. 44-50; Keyes, 1894, p. 125, Plate 16, figs. 1a, 1b; Plate 17, figs. 1a-1e; (pars) Keyes, 1895, p. 181, Plate 19, figs. 1a, 1b; Plate 20, figs. 1a-1e; Troost in Wood, 1909, p. 107.

Palaechinus multipora d'Orbigny, 1850, p. 154.

Melonechinus multiporus Meek and Worthen, 1860, p. 396; Lambert and Thiéry, 1910, p. 120.

Melonites irregularis Hambaeh, 1884, p. 549, Plate C, fig. 2; Jackson, 1896, p. 240; Klem, 1904, p. 41.

Melonites multiporus Miller, 1889, p. 361, text-figs. 364-366; Jackson and Jaggard, 1896, pp. 135-170, text-fig. 1, p. 164; Plate 2, figs. 1-7; Plate 3, figs. 8-17; Plate 4, fig. 18; Plate 5, fig. 20; Jackson, 1896, p. 191, text-fig. 1, p. 240; 1899, p. 131; (pars) Klem, 1904, pp. 2-6, 42, Plate 1, figs. 1a-1e; Plate 2, figs. 4a-4d; Plate 3, figs. 6a-6d, 7a-7e; Plate 4, figs. 8a-8f, 9d; Plate 5, figs. 9a, 9b, 10a, 10b, 11, 12d; Plate 6, figs. 10e, 12a-12e, 13a-13e.

Melonechinus irregularis Lambert and Thiéry, 1910, p. 121.

This species is known from very extensive and usually well preserved material from St. Louis, Missouri. I have enjoyed the privilege of studying material in many museums, includ-

ing the choice specimens in Mr. Frank Springer's collection recently acquired by him from Professor Hambach of St. Louis. In my earlier paper with Professor Jaggar (1896) we published a detailed description and discussion of this species, so that here I shall give only the systematic description of the species, followed by a discussion of new observations.

The test is high and spheroidal, with low, rounded, melon-like ribs in ambulaeral and interambulaeral areas. A small but nearly perfect specimen, free from all distortion (Plate 55, figs. 1, 2), measures 54 mm. in height and 62 mm. in diameter through the mid-zone; the ambulaera at the mid-zone measure 16 mm. in width, the interambulaera 20 mm. in width. A larger specimen, also quite free from distortion (Plate 60, fig. 1), measures 65 mm. in height, 79 mm. in diameter through the mid-zone; the ambulaera at the mid-zone measure 20 mm. in width and the interambulaera 25 mm. in width. A very large specimen, the largest that I have seen (Plate 55, fig. 3), is incomplete ventrally, and the figure shows practically the whole specimen. It measures 123 mm. in diameter through the mid-zone. Comparing this with smaller specimens, the estimated height is about 101 mm.; the width of the ambulaera at the mid-zone is 34 mm., and of the interambulaera 39 mm.

The ambulaera are somewhat narrower than the interambulaera, with ten columns of plates at the mid-zone (Plate 56, fig. 4). These consist of wide ocluded plates, extending from the middle of the area outward, narrow demi-plates extending from the interambulaeral contact inward, and three irregular columns of isolated plates in each half-area. Occasionally, only eight columns of ambulacral plates can be counted at some planes, but the character is to have ten columns. The ocluded plates in the median line are elevated in low, gently rounded, melon-like ribs, and demi-plates bevel over the interambulaerals on the adradial sutures, as I showed previously (1896, p. 141, Plate 2, fig. 5). The pore-pairs are situated in shallow valleys on either side of the ambulaeral areas and lie in the outer portion of each plate, the pores being surrounded by a peripodium (Plate 56, fig. 12); but this structure is usually lost in erosion. Ambulaeral plates bear small secondary tubercles and spines, similar to those of the interambulacral areas. As seen from the interior (Plate 56, fig. 5), the ocluded plates are narrower than on the exterior, and demi-plates opposite horizontal interambulacral sutures are higher and laterally fan-shaped (compare text-fig. 244, p. 338). The pore-pairs on the interior of the test lie near the outer border of the ocluded plates, the inner border of the demi-plates, and near the center of isolated plates, instead of all near the outer border of plates as seen from the exterior of the test (Plate 56, figs. 4, 5), (p. 61).

Ventrally, near the peristomal border the ambulaera have four columns of plates (Plate 56, figs. 2, 3; Plate 57, fig. 1), and the complex character of the ambulaerum is built up passing dorsally, as later described in detail. Dorsally, near the oculars in the placogenous zone (Plate 56, fig. 6) a simpler condition also exists as a localized stage, and, passing ventrally to earlier built plates, the complex character is rapidly built up, as discussed later in detail.

The interambulacra are a little wider than the ambulacra and are gently rounded up in moderate melon-like ribs, laterally sloping gradually down to the adradial sutures (Plate 55, figs. 1-3; Plate 60, figs. 1, 2). The ribs are quite distinct from those of the nearly allied *M. liratus* (Plate 54, fig. 4), in which the ribs are high and much more steeply rounded in the ambulacra, and also are more sharply elevated laterally in the interambulacra. The interambulacra of *multiporus* have typically eight or nine columns of plates in each area, very rarely only seven columns. Typically, there are seven columns of plates at the mid-zone, the eighth column coming in a little later (text-fig. 245, p. 382; Plate 57, fig. 1). This is the character in the specimens shown in Plate 55, figs. 1, 2, and Plate 60, fig. 1. In addition, there may be a ninth column appearing dorsally in one or more to all the areas, and this structure of having nine columns is about as frequent as only eight columns in an area. In the specimen, Plate 54, fig. 5, there are nine columns in area A, but eight columns in all other areas. In the splendid great specimen, Plate 55, fig. 3, there are nine columns in areas C, E, and G, the only ones that can be determined with certainty. There are also nine columns shown in two areas in the specimen figured in Plate 56, fig. 11. In the very complete specimen, Plate 60, fig. 2, there are nine columns of plates dorsally in all five areas. As worked out by Jackson and Jaggar (1896, p. 162), it was found that eight columns are a little more frequent than nine in this species. Rarely there are only seven columns in an area (p. 50). In a specimen figured by Jackson and Jaggar (1896, Plate 4, fig. 18) there are evidently only seven columns in one area, but this area has a very retarded development, the fourth column not coming in until much later than in any other specimen known in the family; in another area in this specimen, however, the fourth column originates in the next row after the third as usual (p. 439). When seven columns only are seen in an area, it is usually due to the fact that it is imperfect dorsally, so that that portion where the additional one or two columns appear is wanting. Miss Klem (1904, p. 43) says that in a collection of several hundred specimens one can find any number of specimens with ten, eleven, and even twelve columns in one or more interambulacral areas. I have seen a good many specimens, but none with more than nine columns in an area. The adradial plates are pentagonal as usual in the genus and family, and bevel under the ambulacrals on the adradial sutures. All the plates of median columns are hexagonal or the mechanical equivalent of the same. Interambulacral plates, like the ambulacrals, bear secondary tubercles, similar to those shown in *M. giganteus* (Plate 60, fig. 3; Plate 61, fig. 8). Spines thickly cover the plates in exceptional specimens; the spines are about 3 mm. in length (Plate 56, fig. 13), swollen at the base, and taper gradually to the tip, apparently with slight constrictions. Such constrictions have not been noticed in spines of other Palaeozoic species.

Ventrally, the interambulacra, when perfect, have two plates in the basicoronal row¹

¹ Miss Klem (1904, p. 2) says that there are three plates ventrally when the specimen is perfect. She is certainly mistaken, as discussed on pages 66, 67.

and three plates in the second row; with very rare exception the fourth column originates in the third row and above this zone the additional columns come in at somewhat definite intervals until the full complement is attained, as worked out by Jackson and Jaggard (1896). Dorsally, before reaching the apical disc, the adambulacral columns 1, 2, and some additional median columns may drop out as a character of senescence (Plate 57, fig. 1, text-fig. 246).

It is seen in *Melonechinus multiporus* that there is a perfectly definite arrangement of plates in the interambulacral areas and the same is true of all other members of the Palaeochinidae as I have shown. In this regard remarks made by Mr. Agassiz require consideration. Mr. Agassiz (1881, p. 78) says, "The very peculiar splitting of the vertical rows of coronal plates noticed by Quenstedt in Melonites seems to point to some structural peculiarity in the Palaeochinidae such as I have described in the breaking up of a single interambulacral plate in our recent Echinothuridae. It shows, at any rate, what some of the other genera of the Palaeochinidae plainly show, that we find it impossible to define the number of rows [columns] of coronal plates in the test just as we find it impracticable near the apical system of the regular Echinids to ascertain how many rows of interambulacral plates there are present, as they appear in that region of the test packed in as they best can find place and take up their regular and symmetrical arrangement only later, while we may observe that in the Palaeochinidae this symmetrical arrangement never takes place, the vertical rows of plates running in as best they can, thus forming another important embryonic character of the Palaeochinidae." In regard to this statement of Mr. Agassiz's, I have seen no evidence for the splitting of coronal plates in *Melonechinus* or other members of the Palaeochinidae (p. 415). The arrangement of rows [columns] of plates is perfectly definite in *Melonechinus* and other members of the Palaeochinidae as well, as I have shown (p. 383). In fact they are perfectly definite in probably all Palaeozoic Echini. I have examined a good many regular Echini living and fossil and never saw any difficulty in ascertaining near the apical disc how many columns there are. An unsymmetrical arrangement of plates such as Mr. Agassiz assumes is not a primitive character according to the evidence that I know, and would not therefore show the "embryonic character of the Palaeochinidae" even if it existed in that group, which it certainly does not. Mr. Agassiz (1881, p. 81) himself says that *Bothriocidaritis* is "by far the most primitive of all Echinoidea," yet in that type (Plate 1, figs. 1, 2) there is surely no unsymmetrical arrangement of plates.

The peristome is known in *Melonechinus multiporus* only, in the family of the Palaeochinidae, and here known only from a single specimen which is in the Princeton University Museum Collection 1,464. As a whole, the specimen is neither striking nor especially good, and I found it in exchange material. This unique structure is shown in Plate 56, fig. 7, as it occurs in the specimen, and with some restoration to make clearer the relations of parts in Plate 56, fig. 8, and text-fig. 48, p. 80. Orally in areas J and D there are two ambulacral plates somewhat larger than other plates of the peristomal area. These plates I consider as the primordial

ambulacral plates which typically occupy this position in all regular Echini (p. 82; text-figs. 40-51, p. 80). The existence of two plates in an area on the peristome adorally implies that *Melonechinus* in an early stage had only two columns of ambulacral plates in an area (represented by this one row of two plates), as in the young, probably, of all other regular Echini (Plate 3, fig. 7). Passing aborally, the ambulacral plates of the peristome consist of many rows in each area; also the number of plates in each row increases to the periphery of the area, where there are more plates in a row than in the basicoronal row of the corona proper. In the inter-radial areas of the peristome there are some non-ambulacral plates, three in area A, and two or more in areas E and I. In the reconstruction (Plate 56, fig. 8) I have assumed that three is the typical number and have shown such in the two areas figured. The number is not of apparent significance, but it is important that this peristome representing the family has both ambulacral and non-ambulacral plates, and that the ambulacral consist of two plates in a row adorally, passing to more plates in a row aborally. The Archacocidaridae is the only other family of Perischoechinoida that has both ambulacral and non-ambulacral plates on the peristome, and in this feature both families make an approach to the character seen in the Cidaroida (text-figs. 46-48, p. 80; pp. 82, 85).

The apical disc is small in *Melonechinus multiporus*. In six specimens quite free from matrix and with this structure in place the apical discs measured proportionately from 13 to 16% of the diameter of the tests (pp. 362, 367). The apical disc has all ten ocular and genital plates preserved, or part of them, in numerous specimens (Plate 54, fig. 5; Plate 55, figs. 2, 3; Plate 56, fig. 6; Plate 57, fig. 2; Plate 60, figs. 1, 2; text-fig. 163, p. 149). The oculars are small and imperforate, and separate the genitals, meeting the periproct with the whole width of each plate and ventrally cover the ambulacra and laterally the interambulacra in part on each side, as best seen in Plate 56, fig. 6. The genital plates are wide and high, and have typically three or four pores each (Plate 57, fig. 2). In one case (Plate 60, fig. 2, area G) a genital has only two pores and apparently no pores have been obliterated. Not infrequently one or more pores are obliterated so that the number existent has to be judged somewhat from the position of those found; also pittings of erosion are sometimes confusing to distinguish from actual pores. Dr. Keyes figured a specimen with a single genital pore in a plate which also shows numerous madreporic pores. I have not seen one genital pore only, nor madreporic pores in this species or any other species of the genus (p. 363). The periproctal plates are unknown in this species, which is peculiar, as so many excellent specimens are known. The structure, however, was doubtless similar to that of *M. stewartii* (Plate 56, fig. 1).

The lantern for the genus is known only in this species, and only partially here (Plate 56, figs. 9, 10). I can add little to what was previously shown by Meek and Worthen. The lantern is inclined, pyramids wide-angled, foramen magnum moderately deep, and the teeth extend ventrally a considerable distance beyond the tips of the half-pyramids (p. 363).

The specimen which Professor Hambach described as *Melonites irregularis* I agree with Dr. Keyes in considering referable to *multiplus*. Hambach described *irregularis* as having from six to ten columns of plates in an ambulacral area and from five to seven columns of plates in an interambulacral area. This description is ambiguous, as I earlier stated (1896, p. 240). Having studied the holotype (Plate 72, fig. 12), I find that there are ten columns of plates in an ambulacral area at the mid-zone, as in *multiplus*. In three interambulacral areas there are seven columns of plates at the mid-zone, as is usual at this zone in *multiplus*, p. 377, but two areas are preserved ventrally only, and in these there are but five columns, the ventral character of most species of the genus. The specimen is poorly preserved, and no eighth columns were seen dorsally. Very likely none existed, as it is a small and presumably young individual. There is no reasonable basis for separating it as a distinct species, but rather it may be considered a small and immature *multiplus*. Hambach's published figure was incorrectly oriented as gathered from the ventral introduction of columns.

The location of the type of *M. multiplus* is unknown; I am informed that it was probably destroyed by fire, a cast is in the Museum of Comparative Zoölogy, 3,226. This species has been found in great abundance in the St. Louis Group, Lower Carboniferous, St. Louis, Missouri. Slabs bearing twenty or more specimens occur in several museums, also a number of choice specimens free from the matrix. Many specimens from this locality have been studied in the Museum of Comparative Zoölogy, where there are some 75 specimens; Yale University; Mr. Frank Springer's collection; Princeton University; Munich; Berlin; Strassburg; the British Museum, and others. Keyes in localities for *multiplus*, gives Clarksville and Charlotte, Tennessee. Miss Klem gives other localities taken from species she considers synonyms, but which I treat as distinct. Troost also credits the species to Tennessee. All material I have seen is from St. Louis, which is the only assured locality for the species.

In my earlier paper (1896, p. 191, etc.) I worked out in part the development of the ambulacrum in *Melonechinus multiplus* and compared the same with the structure in related genera; but with more material and fuller knowledge additional facts and relations have come to light. The ventral development, which is shown by the plates built in the youth of the individual, presents a fairly complete series of stages, as shown in Plate 56, fig. 3; Plate 57, fig. 1, area J; text-fig. 245. Close to the peristome there are typically four columns of plates, which consist of wide occluded and narrow demi-plates in each half-area. This is like the condition characteristic of *Lovenechinus* at the mid-zone, and also like the third stage in the development of *Oligoporus*, as shown diagrammatically in text-fig. 237, p. 231. Proceeding dorsally, in *multiplus* (Plate 56, fig. 3) scattered isolated plates appear in the middle of each half-area. This as a stage is comparable to the adult character of *Oligoporus*. Again, passing dorsally, the isolated plates become frequent enough so that they form a vertical column (Plate 56, fig. 3). We have therefore in this arrangement a stage with six columns of plates which is

characteristic of the mid-zone in the lowest species of the genus, as *M. springeri* (text-fig. 237, p. 231). Again, proceeding dorsally, in *multiplus* we next find two columns of isolated plates in each half-area (Plate 57, fig. 1, area J; text-fig. 245); these with the demi- and occluded plates form a stage with eight columns of plates, which is characteristic of the species *M. indianensis* (text-fig. 237, p. 231). At the mid-zone in *multiplus*, and for some distance below and above the same, the full species character of ten columns of plates exists (Plate 56, fig. 4; Plate 57, fig. 1). Thus do typical stages in development repeat the characters seen as adult features in lower genera, or lower species in the genus. As a case of extreme regressive radial variation, in area B of text-fig. 245 and Plate 57, figs. 1, 3, it is seen that a few plates ventrally near the peristomal border are primaries, completely crossing the half-areas. This condition was not seen in any other specimen in the genus; as a reversionary stage, it is comparable to the typical adult character of *Palaeochinus* and to the youthful ventral character of *Maccoya*, *Lovenechinus*, and *Oligoporus* (text-fig. 237, p. 231), (p. 19).

Turning to the dorsal portion of the ambulacrum in *Melonechinus multiplus*, we find that close to the ocular in the placogenous zone in area J (Plate 56, fig. 6; Plate 57, fig. 2; text-fig. 245) there are two ambulacral plates only. In this zone there may be three plates as shown in other areas, but my figures show that one primary plate in each half-area may be found, when as a feature this may be considered a localized stage comparable to the adult typical character of *Palaeochinus*, and to a similar dorsal localized stage in lower genera or other species in the genus (text-fig. 237, p. 231). Proceeding ventrally, in *multiplus* we find next a stage with four plates in a row (Plate 56, fig. 6), which is comparable to the typical character of *Lovenechinus* (text-fig. 237, p. 231). Again, passing ventrally, we next find a stage with six plates in a row (Plate 56, fig. 6); this is comparable to the typical character of *Melonechinus springeri* (text-fig. 237, p. 231). Again, passing ventrally, we next find a stage with eight plates in a row (text-fig. 245; Plate 57, fig. 1), which is comparable to the typical character in *M. indianensis*. Thus do dorsal localized stages, passing ventrally in the progressive development of plates built late in life, present stages which are quite comparable to those seen in youthful development, also to the typical adult characters of lower genera or species in the genus (p. 366).

Jackson and Jagger (1896) worked out the development of the interambulacra in this species, illustrating it by a number of figures and also by tabulations. I have nothing to add to that except to give the arrangement in an exceptionally perfect specimen, lately in Professor Hambach's and now in Mr. Frank Springer's collection. This specimen (Plate 55, figs. 1, 2) is not very large, but is free from all matrix and distortion so that I am able to represent it spread out by the Lovén method with the restoration of only a few plates in the basicoronal row (Plate 57, fig. 1). Before describing the interambulacra of this specimen, attention is called to the diagrammatic text-fig. 246. This is selected to show a typical interambulacral area in this

TEXT-FIGS. 245, 246. — *Melonechinus multiporus*.
 × 2. Adapted from original drawing of Plate 57, fig. 1.
 245. Showing typical character of ambulacrum, also ventral developing and dorsal localized stages.
 246. Interambulacrum showing number of rows on the left, and the introduction of columns on the right.

species, but in its general characters would serve for any species of the family. Lines are drawn through succeeding rows and numbered consecutively from one upward. It is seen that every plate is accounted for and that the angle representing each row, as indicated by dotted lines, deepens progressively passing dorsally. The row in which a given column makes its appearance is indicated on the right side, and the number of the rows from the base or peristomal border is seen in the left side of the diagram (p. 378).

As column 1 is theoretically considered as arising in the primordial interambulacral plate (text-figs. 22-31, p. 70), which has been resorbed, there is no number to represent the row in which it originates on the right side of text-fig. 246. In this choice specimen the introduction of the earlier columns as added can be readily seen in the photographic figure (Plate 55, fig. 1), but they are all plainly seen in Plate 57, fig. 1, and text-figs. 245, 246. In the basicoronal row the two plates are in place in areas G and I, and one of the two is in place in areas A and C. In area E these two plates are restored as indicated by dotted lines. In the second row there are three plates in all areas, the initial plate of column 3 being hexagonal as usual. In the third row there are four plates in each area, the initial plate of column 4 being a pentagon. This pentagon lies on the right of the center in areas A, E, and I, but on the left of the center in C and G. The initial plates of columns 5 to 8 (with the exception of the initial plate of column 8 in area C), are all pentagonal with a heptagonal plate either on the left or on the right ventral border of the same. Column 5 originates in the center, in areas A and G in the sixth row with a heptagon on the right or left; in area C it originates on the left of the center (unusual for odd-numbered columns) in the sixth row with a heptagon on the right, and in areas E and I, column 5 originates in the center, in the seventh row with a heptagon on the right. Column 6 in areas A and E originates in the tenth row on the left of the center with a heptagon on the left; but in area C it originates in the ninth row on the left of the center with a heptagon on the right. In areas G and I the sixth column originates in the tenth row with a heptagon on the right in G and on the left in I. Column 7 originates in the center in all areas, as is typical of odd-numbered columns. In areas A and C this column originates in the thirteenth row with a heptagon on the left. In area E column 7 originates in the fifteenth row with a heptagon on the right, and in areas G and I it originates in the fourteenth row with a heptagon on the left in G, and on the right in I. Column 8 originates in area A on the left of the center in the seventeenth row with a heptagon on the right; in area C column 8 originates on the left of the center in a tetragonal plate in the eighteenth row with a heptagon on the right, also another heptagon on the left ventral border. In area E column 8 originates on the left of the center in the twenty-first row with a heptagon on the left. In area G it originates also on the left of the center, but in the nineteenth row, with a heptagon on the left. Finally, in area I, column 8 originates in the eighteenth row on the right of the center with a heptagon on the left.

In this development of the interambulacrum it is seen that it passes through a series of stages, each of which is represented by two or more columns of plates. A more primitive type with two columns of interambulacral plates is not known in the family of the Palaeoecchinidae but may be reasonably hypothecated (p. 220); we do know, however, types with three, four, five, six, and seven columns as a character in lower species of the genus, or in lower genera of the family. These, while not perhaps the actual ancestors of the species in hand, may be looked upon as representing phases like those which its ancestors did possess. The earliest added columns come in with great regularity in a definite zone in each area, but in later added columns there is some radial variation in the zone of appearance of columns, this variation progressively increasing in degree up to the eighth column. The radial variation may be still more marked, as in Plate 54, fig. 5, in which there are nine columns of plates in area A, but only eight in the four other areas. Here the radii in one specimen present the limit of variation usually found between different specimens of the species as in Plate 60, figs. 1, 2, where fig. 1 has eight columns of plates in all interambulacral areas and fig. 2 has nine columns in all interambulacral areas.

****Melonechinus keepingi* sp. nov.**

Text-fig. 237, p. 231; Plate 58, fig. 1; Plate 59, figs. 1-3.

The test of this species is incomplete but from the fragment that is known it was doubtless spheroidal; melon-like ribs are wanting. This species is known only from the dorsal portion of a corona showing a very good ambulacrum, a fair interambulacrum, and part of a second ambulacrum. It is a light delicate specimen, beautifully preserved in surface detail. This is the second species known from Great Britain; one species is known from Russia, but all others so far described are from North America. The ambulacrum as far ventrally as preserved measures about 30 mm. in width, and the interambulacrum at the same zone is estimated to be about 33 mm. in width.

The ambulacrum adorally, at a zone apparently some little distance above the mid-zone, has twelve columns of plates. These consist of rather narrow (for the genus) occluded plates, narrow demi-, and four irregular columns of isolated plates in each half-area. The occluded plates are proportionately much narrower than in the American species of the genus, and as a concurrent feature the melon-like ribs are wanting. The occluded plates, which are beautifully preserved, have the same arc of curvature as the other ambulacral plates in the area. They are only slightly wider than other ambulacral plates, instead of very much wider as in American species of the genus. This same character of relatively narrow occluded plates without melon-like ribs is also a feature of the British species, *M. etheridgii*, as described. The pore-pairs of *keepingi* are enclosed by peripodia and lie in the outer portion of each ambulacral plate. About two and one half ambulacral plates equal the height of an adambulacral. As far dor-

sally as preserved, there are only two plates in a row, one primary plate crossing each half-area (Plate 59, fig. 1). This as a localized stage of young plates, is comparable to the typical adult character of *Palaeochinus* as shown diagrammatically in text-fig. 237, p. 231. Passing ventrally, we come directly into a stage of two columns of plates in each half-area, demi- and occluded, like the condition characteristic of *Lovenechinus*. Then we pass quickly through a series of stages marked in each half-area by consisting of three columns (like *M. springeri*), then four columns (like *M. indianensis*), then five columns (like *M. multiporus*), finally attaining six columns in a half-area, the species character; all as set forth diagrammatically in text-fig. 237, p. 231. This species has as highly evolved a structure of the ambulacrum as any in the genus, yet its dorsal localized stages yield a complete epitome of the phylogenesis of the type.

The interambulacrum is well preserved dorsally, but part of the plates are wanting in the adoral portion of the area. As there is no dislocation of parts, it seems, however, that the missing plates can be restored with reasonable assurance of accuracy, as indicated by dotted lines (Plate 59, fig. 1). There are only six columns of interambulacral plates: two columns of pentagonal adambulacral and four median columns of hexagonal plates. Dorsally, the plates are nearly rhombic, as is usual in that zone. The adambulacral columns 1 and 2 drop out dorsally, columns 3 and 4 assuming an adradial position, an indication that the specimen, though small, is fully grown and senescent. Ambulacral and interambulacral plates bear numerous small secondary tubercles (Plate 59, figs. 2, 3), and spines which are about 1.5 mm. in length. The spines are relatively stout and tapering from the enlarged base, as usual in the genus.

This species is known from only one specimen from the Lower Carboniferous Limestone of Gledstone, Gisburn, Yorkshire. It was collected by R. H. Tiddeman, and is in the Museum of Practical Geology Collection 6,583. The photograph was taken for me through the kindness of Dr. Kitchin of that museum. The species is named for the late Mr. Walter Keeping who published interesting studies of Palaeozoic Echini.

****Melonechinus etheridgii* (Keeping).**

Plate 58, figs. 3, 4; Plate 59, figs. 5-11.

Melonites etheridgii Keeping, 1876, p. 398, text-figs. 1-6; Jackson, 1896, p. 240; Klem, 1904, p. 44.

Melonechinus etheridgei Lambert and Thiéry, 1910, p. 120.

This species is known from a number of specimens which are considered below in detail. The largest specimen, which was figured by Keeping and selected by him as the type, is a somewhat angular slab measuring 195 by 180 mm. in its larger dimensions. It is covered with a jumbled mass of interambulacral plates, with some nearly complete fragments of ambulacra. A part of this slab is shown in Plate 58, fig. 4 and Plate 59, fig. 6. A second specimen, which is apparently the one referred to by Keeping (1876, p. 398) as being in the British Museum,

is smaller, but is more complete and instructive (Plate 58, fig. 3; Plate 59, fig. 5). Besides these there are several fragmentary specimens known.

The test is large and was probably spheroidal. Melon-like ribs are entirely wanting, and in this character it is like *M. keepingi* and equally differs from American species. The ambulacra form a gently rounded curve, doubtless corresponding to the curvature of the whole test. Keeping thought that the ambulacra formed ten broad elevated ribs; but I see no support for this view. The width of a half-ambulacrum (Plate 58, fig. 3; Plate 59, fig. 5) is about 24 mm., which would give about 48 mm. as the width of the whole ambulacrum at or near the mid-zone. In the large slab which was figured by Keeping, the ambulacra are somewhat narrower, a half-ambulacrum in the widest part seen measuring 16 mm. in width.

In the interambulacra as shown in one specimen there are at least seven columns of plates in an area. There are six columns in place and a left adradial column is restored (Plate 58, fig. 3; Plate 59, fig. 5). On this basis the width of the area would be about 48 mm., the same width as the ambulacrum in the same individual. Keeping assumed that there were eight or nine columns of interambulacral plates. This may be correct, but there is no proof of it. The larger interambulacral plates measure from 8 to 8.2 mm. in width by about 6 mm. in height and 4 mm. in thickness. On the basis of the measurements from the more nearly complete specimen (Plate 58, fig. 3), with ambulacra about 48 mm. in width and interambulacra of the same width, the circumference would be about 480 mm. and the diameter about 153 mm., a very large sea-urchin, exceeding any species known in the genus.

The ambulacra are very wide as shown by the above measurements, and in one specimen (Plate 58, fig. 5) a half-area is quite complete at a zone probably near the mid-zone. This has six columns in the left half-area, which shows that there were twelve columns of plates in a complete area. They are composed of relatively narrow ocluded plates, narrow demi-, and four columns of isolated plates in each half-area. The ocluded plates (as in *M. keepingi*) are relatively narrower than in American species, and are not built up into an elevated melon-like ridge as in American species. The two ocluded columns are clearly distinguished because the pore-pairs are set on opposite sides of the plates (p. 27), which definitely locates the center of the area. Demi-plates bevel over the adambulacrals on the adradial sutures.

In most of the specimens the interambulacral plates are dissociated, so that the number of columns is quite doubtful, but in one (Plate 58, fig. 3; Plate 59, fig. 5) there are one pentagonal adambulacral and five hexagonal median columns in place. To complete the area, at least one left adambulacral column must be added, as indicated by dotted lines. There may have been more than seven columns. With seven columns the interambulacrum has about the same width as the ambulacrum, but, if there were more than seven, then the interambulacrum would be so much the wider. Ambulacral and interambulacral plates bear numerous secondary tubercles and spines. The spines are tapering, the most nearly complete being about 2.5 mm. in length.

This species was the first one described from Great Britain, and, differs from other European species in its robust size and number of interambulacral columns; and it differs from all American species in which the exterior of the test is known by the absence of the melon-like ribs.

Lower Carboniferous Limestone, Clitheroe, Lancashire, Museum of Practical Geology Collection, holotype 6,577; paratype 6,578. Keeping (1876, p. 399) says that these specimens are from the Carboniferous Limestone of Derbyshire, but this is probably a mistake, as the locality given is taken from the original label, and other specimens lithologically identical are known from the Clitheroe locality. Clitheroe, Lancashire, Sedgwick Museum, Cambridge, England, Collection 18, 19, 20; Coplaw, Clitheroe, Lancashire, Museum of Practical Geology, 16,303; between Clitheroe and Chatburn, Lancashire, H. L. Hawkins Collection; Vallis, near Frome, Somerset, British Museum Collection (two specimens) E 1,400; Thornton-in-Craven, Yorkshire, British Museum Collection E 9,540.

The holotype, which is the original of Keeping's figures, is in the Museum of Practical Geology Collection 6,577. A photograph of this specimen taken for me through the kindness of Dr. Kitchin is in part reproduced as Plate 58, fig. 4. It is a large slab covered with numerous dissociated interambulacral plates and twelve more or less complete fragments of ambulacral areas, part of which are turned over so that they are viewed from within. The hexagonal interambulacral plates measure about 8 mm. in width by 6 mm. in height and 4 mm. in thickness. The external views of the ambulacra show no indication of a melon-like ridge. Several of the fragments have six columns of plates, indicating a complete section of a half-area; pore-pairs are in peripodia in the outer portion of each plate, and some of the plates have tubercles and spines in place. In the ambulacra as seen from the interior the plates are more angular, being nearly or quite hexagonal in this view, and the pore-pairs are near the middle of each isolated plate, which is gently curved toward the interior of the test, as shown in Plate 59, fig. 8, which was, however, drawn from another specimen.

The second specimen in the Museum of Practical Geology Collection 6,678, is labeled as Keeping's second type. It is evidently the specimen he referred to (1876, p. 398), although he states that it is in the British Museum. Dr. Bather, after careful search, found no such specimen in the British Museum, and evidently the statement was a mistake or the specimen has since been transferred to the Museum of Practical Geology. It measures 100 mm. in height and 75 to 100 mm. in width, corresponding with Keeping's description. Structurally, it is the most nearly complete specimen known. A photographic figure, which I owe to the kindness of Dr. Kitchin, is given in Plate 58, fig. 3, and a drawing in Plate 59, fig. 5. The ambulacrum shows six columns of the left half-area and some occluded and isolated plates of the right half-area. The interambulacrum has a right adambulacral column and five columns of hexagonal plates. In the figure I have added a left adradial column, but there may have been more

hexagonal columns before this adradial was reached (Keeping assumed that there were eight or nine columns, but this is doubtful). The adambulacral plates show a beveled edge on the adradial suture, and numerous tubercles and spines are present on ambulacral and interambulacral plates (Plate 58, fig. 3).

The third specimen in the Museum of Practical Geology Collection 16,303, has dissociated interambulacral plates and a portion of an ambulacral area seen from within, showing well the central position of pores on the interior of isolated plates (Plate 59, fig. 8).

The specimens in the Sedgwick Museum Collection, Cambridge, England, are from the Aitken Collection, and all consist of small slabs with dissociated interambulacral plates and parts of ambulacra seen from both the exterior and the interior. The interambulacral plates are large, as in the type, and one measured is 8.2 mm. wide by 6 mm. high.

The British Museum has two specimens from Frome, as above listed. They were presented by the Rev. Canon Jackson in 1877. The larger of these two shows a fragment of an ambulacral area and interambulacral plates with tubercles and spines. An adradial plate shows well the beveled adradial face (Plate 59, figs. 9-11). The British Museum specimen from Thornton-in-Craven is small, but shows a very clear portion of an ambulacrum with a few interambulacral plates. There are only four columns of plates in a half-area, and the specimen doubtless came from a ventral or dorsal developing area where the full number of columns of plates characteristic of the species does not exist.

Mr. Hawkins's specimen from near Clitheroe is fragmentary, but has an exceptionally good ambulacrum. There are six columns of plates in a half-area, which measures 11 mm. in width.

****Melonechinus vanderbilti* sp. nov.**

Plate 58, fig. 5; Plate 61, figs. 1-4.

Test large, spheroidal, with strongly marked melon-like ribs. The type and only known specimen is silicified and somewhat distorted; it represents largely a mold of the interior, but part of the plates are in place as siliceous pseudomorphs. The great thickness of the plates is well seen in the photographic figure (Plate 58, fig. 5). Height about 93 mm. and diameter through the mid-zone about 124 mm.; this latter measurement is somewhat exaggerated by lateral compression. Width of an ambulacrum at the mid-zone about 38 mm., width of an interambulacrum about 43 mm.

The ambulacra at the mid-zone have twelve columns of plates composed of wide occluded, narrow demi-, and four irregular columns of isolated plates in each half-area (Plate 61, fig. 1). The pore-pairs are in peripodia and lie near the outer border of each ambulacral plate. These plates bear numerous secondary tubercles like those of the interambulacra (Plate 61, figs. 1, 3). On the interior, as seen from internal molds, ambulacral plates opposite horizontal sutures are

higher and laterally fan-shaped; also pore-pairs lie near the inner border of demi-plates and the middle of isolated plates (Plate 61, fig. 4) instead of near the outer border of each plate as on the exterior (compare Plate 56, fig. 5).

The interambulacra are about equal in width to the ambulacra, and for the most part are preserved as molds of the interior; a few plates, however, are in place at various parts of the test. There are eight columns of plates at the mid-zone and nine further dorsally in each of the five areas. An area drawn mostly from the internal mold is given in Plate 61, fig. 2. The basicoronal plates are restored, as indicated by dotted lines. There are three plates in the second row and four in the third as usual. Column 5 originates in a pentagonal plate in the middle of the area in the seventh row and bears a heptagon on its right ventral border. Column 6 originates in a pentagon on the left of the center in the tenth row and bears a heptagon on its left ventral border. Column 7 originates in a pentagon in the middle in the fourteenth row with a heptagon on its left ventral border. Column 8 originates in a pentagon in the twentieth row on the left of the center with a heptagon on its right ventral border, and column 9 originates in a pentagon in the middle in the twenty-ninth row with a heptagon on its left ventral border. This area shows aberrant variations in three adventitious pentagons, P, P, P, each of which bears a heptagonal plate on its left or right border. Dorsally, the adambulacral columns 1 and 2 drop out at the points X, X, above which columns 3 and 4 assume an adradial position. At the point P', column 5 drops out; at P'', column 8 drops out, so that above this zone there are only five columns, a case of rather extreme senescence. The apical disc is not preserved.

This species differs from *M. multiporus* as it has twelve instead of ten columns of ambulacral plates in an area, also in that it has high instead of low melon-like ribs. It differs from *M. giganteus* in that it has nine instead of eleven columns of interambulacral plates in an area, also it has a much less accelerated development than that species.

Lower Carboniferous, detailed horizon and locality not known, but probably, from its lithological character, from Kentucky or Tennessee. Holotype in Vanderbilt University Collection (Nashville, Tennessee), 220, from which it was kindly loaned me by Professor L. C. Glenn.

****Melonechinus giganteus* (Jackson).**

Text-fig. 237, p. 231; Plate 58, fig. 2; Plate 59, figs. 4, 12-15; Plate 60, fig. 3; Plate 61, figs. 5-9.

Melonites giganteus Jackson, 1896, pp. 172, 240, Plate 4, fig. 19; Plate 5, figs. 21-24.

Melonites multiporus (pars) Klem, 1904, p. 43.

Melonites granulatus Troost in Wood, 1909, p. 107.

Melonechinus giganteus Lambert and Thiéry, 1910, p. 121.

This represents structurally the highest species of the genus and family, and the type is one of the largest and finest of known Palaeozoic Echini. Test high, spheroidal, with strongly

elevated melon-like ribs in ambulacral and interambulacral areas. The type specimen (Plate 60, fig. 3) measures 115 mm. in height; the height through the exact center from the oral to the anal area measures 100 mm. This smaller measurement is due to the ventral and dorsal incurving of the test. The greatest diameter through the mid-zone is 155 mm. This measurement is somewhat affected by dorso-ventral compression, which, while reducing the height, exaggerates the horizontal diameter. Width of the ambulacra at the mid-zone 38 mm., width of interambulacra 41 mm. The plates are very thick, the interambulacral plates at the mid-zone measuring 8.5 mm. in thickness, much exceeding the surface width of the plates, which is about 7 mm. In a fine specimen in Vanderbilt University Collection 222, the ambulacrum measures about 40 mm. and the interambulacrum 45 mm. in width.

Ambulacral areas are wide, with twelve columns of plates at the mid-zone composed of wide occluded, narrow demi-, and four irregular columns of isolated plates in each half-area (Plate 61, fig. 8). The occluded plates in the middle are arched up in high, rounded, melon-like ribs formed by the thickening of the plates (Plate 60, fig. 3). Demi-plates bevel over the adambulacra on the adradial sutures. Pore-pairs are situated in sunken valleys in each half-area; they are surrounded by peripodia and lie in the outer portion of each ambulacral plate (Plate 61, fig. 8). Ambulacral plates are thickly covered with small secondary tubercles like those of the interambulacra (Plate 60, fig. 3). As seen from the interior of the test (Plate 61, figs. 6, 9), occluded plates are narrower than on the exterior, and demi-plates opposite horizontal interambulacral sutures are higher and laterally fan-shaped (compare text-fig. 244, p. 338). In this view pore-pairs, as usual in the genus, lie in the outer portion of occluded plates, the inner portion of demi-plates, and near the center of all isolated plates, instead of near the outer border of all plates, as is the character of the exterior (Plate 61, figs. 5-9), (p. 359).

Ventrally, the ambulacrum of *M. giganteus* presents interesting stages in development. Near the peristomal border there are four columns of plates, narrower demi- and wider occluded in each half-area, as shown in Plate 59, fig. 13. This is like the adult character of the genus *Lovenechinus* (text-fig. 237, p. 231). A little higher up in this same figure single isolated plates appear in the middle of each half-area; this is like the character of *Oligoporus*. Next appear more isolated plates which, being continuous, make a single column of isolated plates in each half-area like the condition in *Melonechinus springeri*, the simplest ambulacral condition that is referable to the genus *Melonechinus* (text-fig. 237, p. 231). A four-column stage like that of *Melonechinus indianensis* would be the next to follow the three column stage, but, owing to local imperfections, it was not ascertained in *giganteus*, so that a gap occurs at this point. A little higher up, however, we find a stage in which there are five columns in a half-area (Plate 59, fig. 12); this is like the typical condition at the mid-zone in *Melonechinus multiporus* (text-fig. 237, p. 231). Still higher appear the six columns in a half-area, which is the species character. Thus the ventral stages in development of the ambulacrum in this highest species of

the genus repeat very fully the adult character of representative lower species and genera in its series. Dorsal localized stages could not be ascertained in *Melonechinus giganteus*, but in the diagram (text-fig. 237, p. 231) such stages are supplied from *Melonechinus keeplingi*, which at the mid-zone has twelve columns of ambulacral plates, and therefore in this respect represents the same structural differentiation as *giganteus*.

The interambulaera of *Melonechinus giganteus* are slightly wider than the ambulaera, and are arched up in strong melon-like ribs which outwardly are gently curved and laterally dip steeply down to the adradial sutures (Plate 60, fig. 3). There are eleven columns of plates in an area at or above the mid-zone (Plate 59, fig. 14; Plate 61, fig. 8). This is the highest number known in the genus and family, and therefore, as *giganteus* has as great a number of ambulacral plates as are known, it is considered the most highly evolved species of the genus and family yet discovered. The interambulaeral plates bear many secondary tubercles, there being about twenty-five on the larger plates (Plate 59, fig. 15). The spines are not preserved.

The structure of the interambulaera of the type was described in detail and the point of origin of columns tabulated in my earlier paper (1896, pp. 174-182). Eleven columns were ascertained in four of the five areas, and it was estimated that there are about 1,550 interambulaeral plates in the specimen. It has not only more columns of interambulaeral plates than any other species of the genus, but, as a natural corollary, it has a more accelerated development than lower species of the genus. Considering here only one area, that figured (Plate 59, fig. 14), it is seen that plates of the basicoronal row are wanting, but there were doubtless two, as restored in Plate 59, fig. 13. Assuming these two as a basal row, there are three plates in the second row and four in the third as usual in the whole family. The fifth column originates in the fifth row (very early), the sixth column in the eighth row, the seventh column in the tenth, and the eighth column in the fourteenth row, all very early as compared with the zone at which these columns originate in other species of the genus (compare text-fig. 246, p. 382; Plate 57, fig. 1). The ninth column originates in the sixteenth row in a small tetragonal plate, in which the two sides wanting are compensated for by the two heptagons, H' and H'', on its left dorsal and right ventral borders. The hexagon A lies on its left ventral border. In the seventeenth row there are only eight plates, but in the eighteenth row the ninth column starts again with a pentagonal plate bearing a heptagon, H, on its right ventral border as usual. The same anomaly occurs in the origination of the ninth column in three other areas in this superb specimen, showing a strong tendency to a parallel radial variation. The tenth column originates in the twenty-second row, just below the mid-zone, about the same zone in which the eighth column ordinarily originates in *M. multiporus* (Plate 57, fig. 1). The eleventh column originates in this area (Plate 59, fig. 14) in the twenty-ninth row, or in other areas a trifle earlier. Dorsally, as a senescent character, it drops out before reaching the apical disc. In the specimen in Vanderbilt University Collection 222, the eleventh interambulaeral column has already

been attained at the mid-zone, somewhat earlier than in the type. A fragmentary specimen in the United States National Museum has eleven columns at a point which is probably very near to the mid-zone (Plate 61, fig. 8).

Dorsally, there are obscure traces of genital and ocular plates in the type, but structural details could not be made out. As closely as it can be ascertained the apical disc measures about 22 to 25 mm. in diameter, which is 15 to 16 % of the diameter of the test. In this proportion it agrees with the measurements obtained in *Melonechinus multiporus* (p. 379).

This species is very distinct from any previously described. It differs from *multiporus* in the character of the highly elevated melon-like ribs, in the number of columns of ambulacral and interambulacral plates, and the accelerated development of the interambulacral area. I think Miss Klem is entirely mistaken in considering *giganteus* a synonym of *multiporus*, but it should be noticed that she includes in the synonymy of *multiporus* several species that are here considered distinct. Miss Wood (1909, p. 108) thinks that the *Melonites granulatus* of Troost, is referable to *giganteus*, and studying the type, I quite agree with her, although my first impression was that it should be considered a distinct species. In this specimen (Plate 58, fig. 2; Plate 59, fig. 4), which is fragmentary, there is a half-ambulacrum with six columns of plates, indicating twelve columns in the area. In the interambulacrum there are an adambulacral and five hexagonal columns in place, but the right part of the area is wanting, so that the total number of interambulacral columns is unknown. With present evidence it can safely be referred to *giganteus*.

Lower Carboniferous, Bowling Green, Kentucky, holotype, Museum of Comparative Zoölogy Collection 2,989; St. Louis Group, Clarksville, Tennessee, United States National Museum 42,340; Mississippi Group, Lower Carboniferous, Cumberland Gap, Tennessee (the holotype of *Melonites granulatus* Troost) United States National Museum 39,909; no detailed horizon or locality, probably St. Louis Group, Tennessee, Vanderbilt University Collection (Nashville, Tennessee), 222.

The several specimens of this species studied are sufficiently considered above, excepting the National Museum specimen from Clarksville, Tennessee. This specimen, though fragmentary, is very instructive. From it is gathered a very good section across an interambulacrum and half-ambulacrum (Plate 61, fig. 8). In the ambulacrum there are six columns of plates in the half-area, pore-pairs are in clear peripodia near the outer border of each plate, and numerous secondary tubercles exist. The interambulacrum shows the introduction of column 11 in a pentagonal plate with a heptagon on its right ventral border. A section of an ambulacrum seen from within (Plate 61, fig. 9) shows plates more angular than on the exterior and convex toward the interior. The pore-pairs lie toward the outer border of the occluded plates, the inner border of demi-plates, and near the middle of isolated plates, instead of near the outer border of all plates, as seen on the exterior. In order to compare critically the inner and outer faces, these views are shown in the same individual plates in Plate 61, figs. 5, 6, and 7. In these

figures the relative size, angles, and position of pores of ambulaeral plates are seen. The adambulaeral plates on the interior are much wider than on the exterior. The other interambulaeral plates are narrower and lower on the interior than on the exterior, due to the smaller space occupied on the interior by thick plates in a curved test.

Family LEPIDESTHIDAE Jackson.

Lepidocentridae (pars) Lovén, 1874, p. 39; (pars) Jackson, 1896, p. 241; (pars) Klem, 1904, p. 16.

Palaecechinidae (pars) Lovén, 1874, p. 40.

Archaeocidaridae (pars) Lovén, 1874, p. 42; (pars) Duncan, 1889a, p. 8; (pars) Zittel, 1879, p. 485.

Melonitidae (pars) Zittel, 1879, p. 484; (pars) Duncan, 1889a, p. 15.

Lepidesthidae Jackson, 1896, pp. 206, 241; Tornquist, 1897, pp. 730, 734; Gregory, 1900, p. 304; Klem, 1904, p. 22; Lambert and Thiéry, 1910, p. 123.

Hybochinidae Tornquist, 1897, pp. 732, 734.

Rhoechinidae (pars) Lambert and Thiéry, 1910, p. 121.

This family is enlarged from what it was as I first published it, to include certain old genera and one new one. It presents a wide range of characters, yet is fairly homogeneous as a whole. As a family it is related to the Palaecechinidae, from which it is distinguished essentially by the fact that the plates are imbricate. Test spheroidal, elliptical, obovate, or flattened. Ambulacra are narrow or wide, with, in each area at the mid-zone, from two to twenty columns of plates which imbricate weakly or strongly adorally, and laterally bevel under the adambulacral plates. As in the two lowest genera of the Palaecechinidae, the lowest genera of this family (*Lepidochinus*, *Perischodomus*) have only two columns of plates in an ambulacral area, but other genera have from four columns upward. Pore-pairs are in peripodia, situated nearest the next adjacent interambulacrum or exceptionally (*Pholidocidaris*) near the middle of each plate. The ambulacra ventrally and dorsally (as in the Palaecechinidae) are simpler than at the mid-zone, when that area is complex. Ambulacral plates bear secondary tubercles and spines only, or (*Meekechinus*) small primary with secondary tubercles. In the character of the number of ambulacral columns, this family includes the most specialized of Palaeozoic Echini.

The interambulacra are wide or narrow with from three to thirteen columns of plates at the mid-zone in each area. The plates are thick or thin, and imbricate aborally and from the center laterally and over the ambulacrals on the adradial sutures. This last is an important point, as in the Palaecechinidae, in which imbrication is lacking, interambulacral plates bevel under (not over) the ambulacrals. Ventrally, apparently always in this family (Plate 64, fig. 2), the primordial interambulacral plates are in the basicoronal row, there being, as far as known, no resorption of the base of the corona. From the basicoronal row passing dorsally, there are two plates in the second row and three in the third, dorsal to which additional columns, if developed, come in as in other Palaeozoic types. Interambulacral plates bear secondary tubercles and spines only, or primary with secondary tubercles and spines.

The peristome where known has ambulacral plates only. Oculars are insert or exsert, and imperforate or exceptionally with one pore (*Lepidechinus*, Plate 63, fig. 8), or two pores (*Lepidesthes formosa*, Plate 68, fig. 5). The oculars ventrally cover the ambulacra and laterally the interambulacra in part on either side. The genitals are high and wide with from one (*Lepidechinus*, Plate 63, fig. 8) to many pores each. A madreporite is clearly existent in some species. Plates of the periproct are numerous and angular, much as in other Palaeozoic types. The lantern is inclined, teeth grooved, pyramids wide-angled, with moderately deep foramen magnum; epiphyses are narrow, capping the half-pyramids, and braces are of the character usual in all regular Echini.

LEPIDECHINUS Hall.

- ¹ *Lepidechinus* Hall, 1861, p. 18; (pars) 1868, p. 295; (pars) 1870, p. 339; (pars) Lovén, 1874, p. 44; A. Agassiz, 1874, p. 648; non 1892, p. 74; (pars) Duncan, 1889a, p. 12; (pars) Keyes 1895, p. 192; (pars) Jackson, 1896, pp. 226, 242; (pars) Klem, 1904, p. 20; (pars) Lambert and Thiéry, 1910, p. 122.
- ² *Rhocchinus* Keeping, 1876, p. 37; (pars) Duncan, 1889, p. 205; 1889a, p. 14; (pars) Jackson, 1896, pp. 200, 239; (pars) Tornquist, 1897, p. 18; (pars) Klem, 1904, p. 27; Lambert and Thiéry, 1910, p. 122.

Test spheroidal, ambulacra narrow with two columns of plates in each area throughout. Plates all primaries, pore-pairs uniserial or slightly biserial at the mid-zone. The ambulacral plates imbricate moderately adorally, and laterally bevel under the adradials. Interambulacra are wide at the mid-zone with from four to eight columns of plates in each area in the known species. Interambulacral plates are relatively thick, rounded somewhat in outline, but pentagonal in adambulacral and hexagonal in median columns. They imbricate aborally and from the center outward and over ambulacrals on the adradial sutures. The primordial interambulacral plates are in the basicoronal row (Plate 64, fig. 1). The surface of interambulacral plates bears secondary tubercles only. Peristome with ambulacral plates only. Apical disc as known in one species (Plate 63, figs. 7, 8) with oculars exsert, each with one pore, at least as seen from within, and genitals high and wide, each with one pore. As the apical disc is known only from one specimen, and that one seen from within (Plate 63, figs. 7, 8), it is quite possible that an external view or other species might show other characters. Periproctal plates are unknown. The lantern is inclined, teeth grooved, and pyramids wide-angled, with moderately deep foramen magnum.

The type species is *Lepidechinus imbricatus* Hall, from the Lower Carboniferous of America.

¹ *Lepidechinus* as here described includes *L. imbricatus* Hall, the type, but not *L. rarispinus* Hall, which is referred to the genus *Hyattechinus*, p. 292.

² *Rhocchinus* as used by Duncan includes *R. irregularis* Keeping, here referred to *Lepidechinus*, and also species of *Palaeochinus*, p. 303. In this he was followed by Jackson (1896), Tornquist (1897), and Miss Klem (1904). Lambert and Thiéry (1910, p. 123) point out this error in the application of the name *Rhocchinus*.

This genus is considered the lowest member of the family, and is very near to *Palaeochinus*, which is also considered the lowest member of its family. *Lepidechinus* differs from *Palaeochinus* chiefly in the fact that the plates are imbricate and that adambulacral plates bevel over the ambulacrals instead of ambulacrals beveling over the adambulacrals, as in *Palaeochinus*. Hall in describing *Lepidechinus*, and Keeping in describing *Rhoechinus*, pointed out the close relations of these genera to *Palaeochinus*. Unfortunately Professor Hall did not figure *Lepidechinus imbricatus*, the type, but did figure what he described as *L. rarispinus*, which, however, has very different characters and is here referred to *Hyattechinus* (p. 292). Naturally the understanding of *Lepidechinus* has been taken largely from *rarispinus* with the result that the genus *Lepidechinus* has been misinterpreted. As I have studied and here figure the type, it is hoped that the relations expressed may prove correct.

Mr. Agassiz (1874, p. 648) says, "In Hall's genus *Lepidechinus* the ambulacra and interambulacra lap in opposite directions. Interambulacra in eight rows; outer pentagonal, others hexagonal. Hall, in his Report on the Geology of Iowa, has given us excellent figures of the tubercles, spines, and portions of the ambulacral and interambulacral plates (Pl. XXVI)." This reference is quite mistaken, as in the work and Plate referred to, Professor Hall figured *Archaeocidaris*, not *Lepidechinus*. Hall never figured *Lepidechinus imbricatus*, which has eight columns of plates in an interambulacrum, and which is here figured for the first time (Plate 62, fig. 5; Plate 64, fig. 1). Hall, however, did give a figure of *Lepidechinus* [*Hyattechinus*] *rarispinus*, which has eleven columns of plates in each interambulacral area (pp. 292, 294; Plate 21, fig. 6; Plate 22, fig. 7). Further, Mr. Agassiz (1892, p. 74) says, "Hall's figures of *Lepidechinus* in the Geology of Iowa [1858], Vol. I., Part 2, Plate IX, fig. 10,¹ show three or four plates at the actinal edge." Hall's *Lepidechinus rarispinus* is here referred to *Hyattechinus rarispinus* (pp. 292, 294); his figured specimen, and the only one he did figure (my Plate 21, fig. 6; Plate 22, fig. 7), is a dorsal mold, so that Mr. Agassiz is mistaken in speaking of it as ventral. In *rarispinus* there is a single plate at the actinal (or peristomal) border of the test (not "three or four plates") as I show in three species of *Hyattechinus* (p. 292), as well as in the true *Lepidechinus* (p. 400).

Key to the Species of Lepidechinus.

Four columns of plates in an interambulacral area at the mid-zone . . .	<i>L. irregularis</i> (Keeping), p. 396.
Five columns of plates in an interambulacral area at the mid-zone . . .	<i>L. iowensis</i> sp. nov., p. 397.
Six columns of plates in an interambulacral area at the mid-zone . . .	<i>L. tessellatus</i> sp. nov., p. 397.
Eight columns of plates in an interambulacral area at the mid-zone . . .	<i>L. imbricatus</i> Hall, p. 399.

¹ This reference is incorrect as Hall's figure of *Lepidechinus*, which is *L. [Hyattechinus] rarispinus* was not published in the Geology of Iowa, but in 1868 (and 1870, revised edition) in the Twentieth Report N. Y. State Cabinet Nat. Hist., Plate 9, fig. 10 (see this memoir, p. 292).

****Lepidechinus irregularis* (Keeping).**

Plate 63, figs. 1, 2.

Rhoechinus irregularis Keeping, 1876, p. 37, Plate 3, figs. 6-8; Zittel, 1879, p. 484; Duncan, 1889, p. 205; Jackson, 1896, p. 200; Tornquist, 1897, p. 754; Klem, 1904, p. 30; Lambert and Thiéry, 1910, p. 122.

Palaechinus rutoti Julien, 1896, p. 129, Plate 6, fig. 8; Klem, 1904, p. 36; Lambert and Thiéry, 1910, p. 119.

Palechinus rutoti Tornquist, 1897, p. 753.

Test small, spheroidal, imperfectly known. Ambulacra are narrow, with two columns of low primary plates which imbricate adorally and laterally bevel under adambulacrals. About four ambulacral plates equal the height of an adambulacral. Pore-pairs are uniserial, situated near the outer border of each plate. Interambulacra are broad, with four columns of plates at or about the ambitus, and in the type a trace of a fifth column, as represented by one plate, exists dorsally (Plate 63, fig. 2). These plates imbricate aborally, and from the center laterally and over the ambulacra on the adradial sutures. Externally they bear small secondary tubercles.

Keeping's holotype is a small specimen which I studied at the Sedgwick Museum, Cambridge, England. He naturally made it the type of a new genus (*Rhoechinus*), as it differed so distinctly from *Palaechinus* by the imbrication of its plates. Keeping says of his genus *Rhoechinus* that it differs from *Perischodomus* and *Lepidechinus* in the absence of primary tubercles. This is true in regard to *Perischodomus*, but was a mistake as regards *Lepidechinus*, for the type of that genus and other species here attributed to it have only secondary tubercles. It is to be remembered however that Hall's *Lepidechinus* [*Hyattechinus*] *rarispinus* has primary tubercles (p. 293). The species *irregularis* is clearly referable to Professor Hall's genus *Lepidechinus*, so that *Rhoechinus* becomes a synonym. Professor Duncan overlooked the character of imbrication and used *Rhoechinus* to include species which he separated from the old genus *Palaechinus* M'Coy, as earlier discussed (p. 303).

The specimen described as *Palaechinus rutoti* by Julien with present evidence cannot be distinguished structurally from *L. irregularis*. As Julien says, it has two columns of low narrow ambulacral plates, imbricating adorally, with pore-pairs uniserial, and four columns of interambulacral plates which imbricate aborally, and bear small secondary tubercles only. Four ambulacral plates are equal in height to a pentagonal adambulacral plate. The hexagonal interambulacral plates have a width of 5 mm. and a height of 3 mm.

Lower Carboniferous, Hook Head, County Wexford, Ireland, holotype in Sedgwick Museum Collection, Cambridge, England, 12; near Savigny-Poël-Fol, central France (this is the holotype of *Palaechinus rutoti* Julien, and is in the possession of the family of the late Professor Julien).

****Lepidechinus iowensis* sp. nov.**

Plate 62, fig. 1; Plate 63, figs. 3, 4.

Test spheroidal. Known only from the holotype, which measures 52 mm. in diameter. The ambulacra at the mid-zone are 4.5 mm. in width and the interambulacra 28 mm. in width. The ambulacra are narrow, composed of two columns of low primary ambulacral plates alike throughout the area. Pore-pairs are uniserial, situated near the outer border of each plate. Ambulacral plates imbricate slightly adorally and laterally bevel under the adradials (Plate 63, fig. 4). The interambulacra are broad with five columns of plates in each area. The interambulacral plates are moderately curved outward, are pentagonal in adambulacral and hexagonal in median columns. They imbricate moderately aborally and from the center outward and over the ambulacrals, on the adradial suture line presenting a curved outline (compare *Perischodonus*, Plate 64, fig. 3). The ventral portion and apical disc are wanting, but the lantern is in place and partially visible, as seen from above (Plate 63, fig. 3). The lantern is inclined, so that, with the angle presented, one sees a considerable portion of the inner face of the teeth (compare Plate 27, fig. 5). The teeth are grooved, pyramids wide-angled, and foramen magnum moderately deep. Typical braces are in place. The structure of the lantern as far as gathered from the dorsal view is essentially like that of *Lepidesthes* (Plate 68, figs. 9-14).

Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. The holotype and only known specimen is in Mr. Frank Springer's collection 8,010.

****Lepidechinus tessellatus* sp. nov.**

Plate 62, figs. 2-4; Plate 63, figs. 5-11.

Lepidechinus imbricatus A. Agassiz, 1904, p. 80 (non *Lepidechinus imbricatus* Hall, 1861, p. 18. See p. 299).

Test spheroidal. The holotype (Plate 62, fig. 2) measures 50 mm. in diameter. The width of the ambulacrum at the mid-zone is 5 mm., width of the interambulacrum 25 mm.

The ambulacra are narrow, composed of two columns of low primary plates in each area. Pore-pairs are uniserial, situated near the outer end of each plate (Plate 63, fig. 6). About five to six and a half ambulacral plates equal the height of an adambulacral. The ambulacral plates imbricate adorally and laterally bevel under the adambulacrals. From this beveling it occurs that the ambulacral plates on the interior of the test (Plate 63, fig. 7) are wider than on the exterior, and also on the interior the pore-pairs are in the middle of the half-areas instead of near the outer end of each plate, as on the exterior (p. 60).

The interambulacra are wide, composed of six columns of plates at the mid-zone in each area. In the paratype (Plate 63, fig. 9) the sixth column originates below the mid-zone, and

in the holotype (Plate 63, fig. 6) one column, either 5 or 6, drops out dorsally with a pentagonal plate, indicating senescence. The interambulacral plates are curved on the outer surface and bear secondary tubercles only. They are slightly rounded on the suture lines and imbricate moderately aborally and from the center laterally and over the ambulacra. Adambulacral plates are pentagonal, rounded on the adradial sutures (compare Plate 64, fig. 3). The plates of the median columns are hexagonal. On the interior of the test (Plate 62, fig. 3; Plate 63, fig. 7) the interambulacral plates are more sharply angular than on the exterior, and adambulacral plates are not rounded on the adradial sutures (compare text-figs. 32, 34, p. 75).

The ventral portion of the test is unknown. Dorsally, as seen from within (Plate 62, fig. 3; Plate 63, figs. 7, 8) the apical disc is in place; it is small, measuring 9 mm. in diameter. The whole of this specimen is not known but it corresponds nearly enough with the holotype so that it was at least fully as large. On this basis the diameter of the apical disc as seen from within would be proportionately about 18 % (or less) of the diameter of the test. Several ocular and genital plates are in place. The oculars are triangular, fully exsert, each being shut out from the periproct by the contact of the two adjacent genitals, a rare character in the Palaeozoic, but like the dominant Mesozoic and the youthful character of modern Echini (p. 89). Each ocular has one pore near the ventral border, but as this is an internal view, it is not certain that the pore reached the surface (p. 89). The oculars ventrally cover the ambulacra and laterally in part the interambulacra on either side, the young interambulacral plates being in contact with the oculars (pp. 62, 86). This is the specimen to which Mr. Agassiz (1904, p. 80) referred as *Lepidechinus imbricatus*, and in which he noted that the young interambulacral plates originate against the oculars. The genital plates are high and wide, and, as far as preserved, meet in a continuous ring dorsally on the periproctal border. Each genital has a single pore near the middle of the plate. This single pore in each plate is the only case with this character seen in the Palaeozoic, and also the median position is unusual; but it should be remembered that this is an internal view, and in an external view the pores may be nearer the ventral border (p. 171). Genital pores are usually near the ventral border of the plates, but they may be near the middle of the plates in external view, as seen in *Dermatodiadema* (text-fig. 80, p. 104) and *Peltastes wrighti* (Plate 4, fig. 7). The plates of the periproct and the lantern are unknown in this species.

This species differs from *Lepidechinus iowensis* in having six instead of five columns of plates in an interambulacral area. It differs from *Lepidechinus imbricatus* in having six instead of eight columns of plates in an interambulacral area, and also in that the plates are relatively larger, heavier, and less strongly imbricating.

Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa, holotype, Museum of Comparative Zoölogy Collection 3,053; paratype, same museum, no. 3054; second paratype, F. Springer Collection 8,011.

In the holotype, which is in the Museum of Comparative Zoölogy, the dorsal half of the test is preserved (Plate 62, fig. 2; Plate 63, figs. 5, 6). In areas A, E, and I the sixth column drops out passing dorsally and terminates in a pentagonal plate, an apex of which points dorsally; and in areas C and G the fifth column drops out similarly. In area E the fifth column also drops out, but two rows later than column 6. The terminal pentagons in several cases have a heptagonal plate on their dorsal border. These might easily be taken for the point of introduction of columns, but this is the dorsal, not the ventral portion of the test, as shown by the direction of imbrication of plates. This specimen has very clear ambulacral detail which is taken to represent the species character.

In Mr. Springer's specimen (Plate 62, fig. 4; Plate 63, figs. 9-11) the plates are worn, but the imbrication is clear, as shown in Plate 63, figs. 10 and 11. Ventrally there are five columns, the sixth coming in below the mid-zone. The ambulacral plates ventrally are all typical primaries with pore-pairs uniserial, but at the mid-zone in this specimen there is a tendency for alternate plates to be expanded on the lateral border and the plates between narrowed. There is nothing of this seen in the type, but otherwise the specimen has the characters of this species.

The Museum of Comparative Zoölogy specimen, which is seen from the interior, is very interesting (Plate 62, fig. 3; Plate 63, figs. 7, 8). There are three interambulacral and four ambulacral areas. The interambulacral columns in each area are all continued nearly or quite to the apical disc instead of dropping out dorsally, as in Plate 63, fig. 5. The ambulacral plates and apical disc of this choice specimen are considered above.

****Lepidechinus imbricatus* Hall.**

Plate 62, fig. 5; Plate 64, fig. 1.

Lepidechinus imbricatus Hall, 1861, p. 18; 1868, p. 296; Lovén, 1874, p. 44; Keyes, 1895, p. 192; Jackson, 1896, pp. 226, 242; non A. Agassiz, 1904, p. 80; Klem, 1904, p. 21; Lambert and Thiéry, 1910, p. 122.
Lepidocentrus imbricatus Meek, 1874, p. 375.
Lepidechinus intricatus Pomel, 1883, p. 113.

In the type specimen, which is in the Museum of Comparative Zoölogy, the test is spheroidal. The ambulacra at the mid-zone measure about 3 mm., and the interambulacra about 20 mm. in width.

The ambulacra are narrow, composed throughout each area of two columns of low primary plates which imbricate strongly adorally and bevel under the adjacent adambulacrals. Pore-pairs are uniserial, situated near the outer border of each plate. Two and a half ambulacral plates equal the height of an adambulacral. The interambulacra are broad, with, at the mid-zone, eight columns of plates, which are small, curving outward, and rounded on the suture lines. They imbricate strongly aborally and from the center laterally and

over the ambulacrals. The adambulacral plates are pentagonal and rounded on the adradial sutures. Plates of the median columns are hexagonal, but the angles of all these plates are somewhat rounded, not sharply defined, as in the Palaeoechinidae. There are secondary tubercles only on ambulacral and interambulacral plates. No spines are preserved in the type, but in a second specimen in the Museum of Comparative Zoölogy 3,186, there are fine tapering spines, swollen at the base, and measuring up to about 2.5 mm. in length. Ventrally, the primordial interambulacral plates are in the basieoronal row, and, passing dorsally, new columns are progressively added until the full complement is attained below the mid-zone.

Although only partially preserved, it may be safely stated that there are only ambulacral plates on the peristome. The dorsal portion of the test is unknown, and the lantern is not preserved in the type, but in another choice specimen in the Museum of Comparative Zoölogy no. 3,186, from the Wachsmuth Collection, there is a well preserved lantern in place. The pyramids are wide-angled, with ridges for the attachment of interpyramidal muscles, foramen magnum moderately deep, and teeth grooved, all as usual in Palaeozoic species. Some ambulacral plates in this specimen are evidently peristomal plates.

This species, the type of the genus, differs from the other species in that it has more columns of interambulacral plates, also more strongly imbricate plates, both in the ambulaera and the interambulaera. The specimen which I identify as the type has no original label, but bears the diamond-shaped green ticket that Professor Hall used to indicate types. It agrees entirely with Hall's original description. Moreover, the late Professor Whitfield informed me that the type was in the Barris Collection, which was purchased by Professor Louis Agassiz for the Museum of Comparative Zoölogy. Professor Hall in his description says that the interambulacral plates imbricate adorally, "the lower edges of each range overlapping those below; while the plates of the ambulacral areas are imbricating in the opposite direction." The fact that he said that interambulacral plates imbricate adorally is ascribed to incorrect orientation, which has led to a similar interpretation in regard to imbrication in some other cases. Indeed, Professor Hall (1868, p. 296) himself said that he had probably given the direction of imbrication incorrectly in his original description. Professor Hall pointed out that the essential difference of the genus (and species) from Palaeoechinus is the fact that the plates are imbricate. He also considered as a difference the number of columns of interambulacral plates, but this with present understanding is not considered a generic difference. The species differs generically from what Hall described as *Lepidechinus rarispinus*, which species is here referred to Hyatteechinus (p. 292) and figured on Plate 21, fig. 6 and Plates 22, 23.

Burlington Limestone, Lower Carboniferous, Burlington, Iowa, holotype, Museum of Comparative Zoölogy Collection 3,055; another choice specimen especially good for the ventral part of the test, lantern, and spines, Museum of Comparative Zoölogy Collection 3,186; also a fragmentary specimen in the same museum no. 3,056 (original no. 417).

PERISCHODOMUS M'Coy.

Perischodomus M'Coy, 1849, p. 253; 1854, p. 114; Lovén, 1874, p. 40; Keeping, 1876, p. 35; (pars) Duncan, 1889a, p. 10; Jackson, 1896, p. 242; Tornquist, 1897, p. 783; (pars) Klem, 1904, p. 18; (pars) Lambert and Thiéry, 1910, p. 122.

Tretechinus Tornquist, 1897, p. 784.

Test high, spheroidal. Ambulacra are narrow, composed in each area of two columns of low plates. Interambulacra are wide, with many columns of plates (five in the known species) in each area. The interambulacral plates imbricate strongly aborally and from the center laterally and over the ambulacra on the adradial sutures. The primordial interambulacral plates are in place in the basicoronal row. Adambulacral plates bear medium-sized eccentric perforate primary tubercles with secondary tubercles, and median interambulacral plates bear primary and secondary tubercles, or the latter only. Spines are medium-sized primaries and small secondaries. Plates of the peristome are imperfectly known, but apparently are ambulacral only. Oculars are imperforate, genitals low and wide, with numerous pores. The lantern is known from pyramids which are similar to those of *Lepidesthes* and other Palaeozoic Echini.

The characters of this genus are based on *Perischodomus biserialis*, the type species of the genus and the only one which is well known. This genus differs from *Lepidechinus* in that the interambulacral plates, in part at least, bear primary with secondary tubercles. It differs from the other genera of the family in that it has two instead of more than two columns of plates in each ambulacral area. In my earlier paper (1896, p. 242) I included *Perischodomus* in the *Lepidocentridae*, but with fuller knowledge of *Lepidechinus* and *Perischodomus* it seems that both genera belong in the *Lepidesthidae* as primitive representatives of the family.

*Key to the Species of Perischodomus.*¹

Five columns of plates in each interambulacral area, test large *P. biserialis* M'Coy, p. 401.

Five, or perhaps more, columns of plates in each interambulacral area, test small (imperfectly known).

. *P. illinoisensis* Worthen and Miller, p. 406.

****Perischodomus biserialis* M'Coy.**

Text-fig. 30, p. 70; Plate 29, fig. 5; Plate 62, figs. 6, 7; Plate 64, figs. 2-8.

Perischodomus biserialis M'Coy, 1849, p. 253, text-figs. a-c; 1854, pp. 114, 115, text-figs. a-c; Desor, 1858, p. 157; Quenstedt, 1875, p. 374, Plate 75, fig. 13; Lovén, 1874, p. 40; Keeping, 1876, p. 36, Plate 3, figs. 1-5; Jackson, 1896, p. 226; Klem, 1904, p. 18; Lambert and Thiéry, 1910, p. 122.

Perischodomus biserialis Pomel, 1883, p. 114.

Excellent material of this species which I had the opportunity of studying in Dublin, also in London and Cambridge, England, shows the characters of this species well, and is structurally very interesting. M'Coy mentioned two specimens, one in Cambridge, and

¹ *Perischodomus magnus* is considered under *Incertae Sedis*, p. 453.

one in the Griffith Collection in Dublin. Of these, the Cambridge specimen is apparently the one from which M'Coy's figures were taken, and is the original of Keeping's (1876) description and figures here reproduced as Plate 64, figs. 7, 8. M'Coy's second specimen is doubtless the one in the Griffith Collection in Dublin, here reproduced as Plate 29, fig. 5.

The test is spheroidal, and representative measurements are as follows. The Griffith specimen (Plate 29, fig. 5) measures 55 mm. in diameter through the plane J, E, and the interambulacra at the periphery, which is about at the mid-zone, measure 28 mm. in width. On account of crushing, the width of the ambulacra could not be ascertained. The Trinity College specimen, dorsal view (Plate 62, fig. 7), measures about 52 mm. in diameter. The ambulacra at the adoral margin, which is about the mid-zone, measure about 3 mm. in width, and the interambulacra about 25 mm. in width. The Trinity College specimen, internal view (Plate 62, fig. 6), measures about 50 mm. in diameter; the ambulacra at the aboral border, which is about the mid-zone, measure 8.5 mm., and the interambulacra about 19 mm. in width. It is seen from this that the ambulacra on the interior are more than twice as wide as on the exterior. This is due to the strong lateral beveling of ambulacral plates under the adradials. Concurrently the interambulacra are narrower than on the exterior, due largely to the same cause (compare text-figs. 32, 34, p. 75).

The ambulacra are narrow, especially dorsally, and are composed of two columns of low plates which imbricate strongly adorally, and laterally bevel strongly under the adradials. Dorsally, all plates are alike, typical primaries with pore-pairs uniserial (Plate 64, fig. 5), but at the mid-zone alternate plates tend to be narrowed laterally, and may in cases even be cut off from contact with the interambulacra. Pore-pairs are situated in the outer portion of each plate, and are dorsally uniserial, but at the mid-zone are somewhat irregularly slightly biserial. On the interior (Plate 64, fig. 2) ambulacral plates are much wider than on the exterior on account of the lateral beveling, and the pore-pairs are near the middle of each plate. The interambulacra are wide, composed at the mid-zone of five columns of plates in each area. The plates are relatively thick, and imbricate strongly aborally and from the center laterally and over the ambulacrals on the adradial suture. The plates are curved outward on the external surface and rounded on the suture lines. The adambulacral plates are pentagonal, strongly rounded on the adradial sutures. Plates of median columns are rounded polygonal. Each adradial plate bears an eccentric perforate primary tubercle with scrobicule and, in addition, secondary tubercles. Plates of median columns may have a primary tubercle with secondaries, or apparently the latter only. Dorsally, in each interambulacrum in the known specimens two columns drop out before reaching the apical disc. Ventrally, the primordial interambulacral plates are in place in the basicoronal row (text-fig. 30, p. 70; Plate 64, fig. 2). There are two plates in the second row, three in the third, four in the fourth, and five in the fifth row, above which no more columns are added. Primary spines are expanded at the base, tapering, and about 12 mm. long. Secondary spines are similar, but fine and slender, and about 3.5 mm. long.

The peristome is known only fragmentarily, but some ambulacral plates extend on to this area below the primordial interambulacral plates (Plate 62, fig. 6), indicating that there are ambulacral plates only on the peristome, as in *Lepidesthes* (Plate 68, fig. 3).

The apical disc is small relatively to the diameter of the test, but I have no measurements. Of the apical disc in one specimen one small imperforate ocular is in place, situated between the genitals (Plate 64, fig. 8). The genitals are relatively low and wide, with from five to seven or eight pores each. The lantern is known only from pyramids, which are stout and practically like those of *Lepidesthes* (Plate 68, figs. 9–12).

Lower Carboniferous Limestone, Hook Head, County Wexford, Ireland, cotype, Sedgwick Museum, Cambridge, England; also a second specimen in same museum collection no. 16; cotype, Science and Arts Museum Collection, Dublin; Museum of Comparative Zoölogy Collection 3,071; probably the same locality, two specimens, Trinity College, Dublin, Museum Collection; Yorkshire, England, three specimens, British Museum Collection E 10,686 to 10,688; Coplaw, Clitheroe, Lancashire, Museum of Practical Geology 16,310, 16,311; and Ulverstone, Lancashire, the same collection 16,314; Hook Head, Ireland, Museum of Practical Geology 16,315; Clitheroe, Lancashire, Mr. H. L. Hawkins's collection.

The structural characters of the species were gathered from various specimens, and I will now consider these with any additional features which they show. The specimen in the Dublin Science and Arts Museum, from the Griffith Collection, which is doubtless M'Coy's second specimen, is the dorsal half of a test (Plate 29, fig. 5). It occurs on a slab from Hook Head, with two specimens of *Palaeochinus elegans*, one of which is the original of M'Coy's (1844) and Baily's (1865b) figures of that species as earlier described (p. 309). Baily (1865b, p. 63) says of this slab that there are three specimens of *Palaeochinus elegans*, but one of the three is evidently this *Perischodomus*. The specimen is somewhat crushed, and the ambulacral areas are largely hidden by the over-riding of the adjacent adradial plates; but some ambulacral plates are seen. There are five columns of interambulacral plates in each area, the plates showing thin lateral and aboral imbricating edges, also a number of eccentric primary tubercles.

The specimen from Hook Head, described by Keeping, which is also one of M'Coy's original specimens, is one of the best specimens of the species known. This choice specimen (Plate 64, figs. 6–8) is in the Sedgwick Museum, Cambridge, England, where I studied it through the kindness of Professor Woods. At the mid-zone, ambulacral plates are alternately somewhat narrowed, but none was seen actually cut off from contact with the interambulacra. Pore-pairs at the mid-zone are slightly biserial. Some of the ambulacral plates show well the lateral bevel (Plate 64, fig. 6). The interambulacra have the typical species character of five columns of plates in each area, the plates bear primary and secondary tubercles (Plate 64, fig. 8), and two of the columns drop out passing dorsally. The apical disc is the best known in the species. There are one small imperforate ocular and four genitals in place. The genitals have from five

to seven pores each, but one of the plates does not show any pores (Plate 64, fig. 8). In the periproct are several plates, not shown in the figure; they are not in contact, and are turned on edge, but apparently belong to this area. They are small and angular, similar to the periproctal plates of *Lepidesthes* (text-fig. 251, p. 428). Another specimen from Hook Head in the Sedgwick Museum, Cambridge, England, no. 16, has interambulacral plates showing primary and secondary tubercles well, and also primary and secondary spines. The primary tubercles are perforate, with clearly defined scrobicules, and are situated eccentrically. There is one primary tubercle to each adradial plate and also on some plates of the median columns. The secondary tubercles are irregularly scattered over the surface of the plates. Primary spines are stout, swollen at the base, and measure about 11 mm. in length. The secondary spines are small, filiform, and measure about 3.5 mm. in length.

In Trinity College, Dublin, are two fine specimens of *Perischodomus*, which I studied through the kindness of Professor John Joly. There is no locality label, but, judging from the lithological character, they are probably from Hook Head, County Wexford. One of these specimens is a dorsal external view (Plate 62, fig. 7; Plate 64, figs. 3-5). The ambulacra are narrow. Dorsally, all plates cross the half-areas, and pore-pairs are uniserial (Plate 64, fig. 5). At the mid-zone (Plate 64, fig. 4), all the plates meet the middle of the area, but some of them are narrowed outwardly and more or less completely shut out from interambulacral contact. As an associated feature, the pore-pairs are somewhat biserial. There are five columns of interambulacral plates at the mid-zone in each area (Plate 64, fig. 3), but dorsally in each area columns 3 and 4 drop out before reaching the apical disc. Columns 1, 5, and 2, however, extend to the upper limits of the areas. The plates are marginally rounded and strongly imbricating. Each adambulacral plate bears an eccentric primary tubercle, and some of the median plates also have a primary tubercle as seen in Plate 62, fig. 7, but they were overlooked in making the drawing of this specimen.

The second specimen which I saw in the Trinity College Collection at Dublin is an internal view of the ventral side, and is very choice as the only specimen known in this species showing the ventral portion of the test (Plate 62, fig. 6; Plate 64, fig. 2). The ambulacral plates are very much wider than on the exterior. This is ascribed to the lateral beveling of ambulacral plates under the adradials, but, as the exterior of the ventral side is unknown, it may be in part due to a greater width of the ambulacrum ventrally. As seen in this internal view, the ambulacral plates imbricate aborally and bevel over the adradial plates, the reverse condition of that seen from the exterior (compare text-figs. 32, 34, p. 75). The pore-pairs are about in the middle of each plate, a usual character of the interior (compare Plate 20, fig. 10). Adorally some ambulacral plates extend beyond the primordial interambulacral plates on to the peristomal area and by their position (Plate 62, fig. 6) indicate that ambulacral plates alone existed on the peristome, as in other members of this family and all of the *Lepidocentridae*.

(p. 284). The interambulacral plates in this internal view (Plate 62, fig. 6; Plate 64, fig. 2) imbricate adorally and from the sides toward the center of each area; also they bevel under the ambulacral plates on the adradial suture. All this is just the reverse from what is seen from the exterior (compare text-figs. 32, 34, p. 75). The plates of the interambulacral areas are nearly complete, but are restored in part, as indicated by dotted lines (Plate 64, fig. 2). In four areas the primordial interambulacral plate is in place in the basicoronal row (compare text-fig. 30, p. 70), indicating that there is no resorption of the corona by the advance of the peristome, the same being true as far as known of other members of this family, of *Bothriocidar*is, and all of the *Lepidocentridae*. In the second row there are two plates in each area. The initial plate of column 2 is represented on the left in this internal view, which is the equivalent of the right as seen from the exterior, and the same method has been adopted in other cases of internal views (Plate 23, fig. 1). In the third row there are three plates, the initial plate of column 3 being in the center. In the fourth row there are four plates in each area. The initial plate of column 4 is on the left of the center in areas A, C, E, and I (which is the equivalent of the right as seen from the exterior), but in area G the initial plate of column 4 is on the right of the center (which is the equivalent of the left as seen from the exterior). The initial plate of column 5 is in place in the fifth row in areas E and I, and is restored in area C, but areas A and G are not shown above the fourth row. This choice specimen shows that in *Perischodomus* there is no resorption of the base of the corona, and, as a result, the primordial interambulacral plates are in place. It also shows that succeeding interambulacral columns are added rapidly, one in each succeeding row as built, the fifth column coming in immediately after the fourth, indicating a markedly accelerated development, much in excess of anything known in the *Palaeochinidae*, but similar to that characteristic of many of the *Lepidocentridae*. This acceleration, with the small number of columns attained, which is five, and the early dropping out of two columns dorsally, marks *Perischodomus biserialis* as a very peculiar type.

In the Museum of Practical Geology Collection 16,314, is a specimen of this species from Ulverstone, Lancashire, which consists of ambulacral and interambulacral plates with excellent primary and secondary spines. The longest primary spine, which is not complete distally, measures 13 mm. in length, and 1.5 mm. in diameter in the middle of the shaft. The spines are swollen at the base, nearly cylindrical, but taper gradually to the end; smooth throughout with no spinules. If fine striation existed, as is likely, it is worn off. The secondary spines are slender, and measure about 3 mm. in length. This is the best specimen for the spines that I have seen. In the fragment of the ambulacrum, alternate plates are barely pinched off from interambulacral contact, and pore-pairs are biserial. Another specimen in the same collection, 16,310, from Coplaw, Clitheroe, Lancashire, consists of dissociated interambulacral plates and spines. The tubercles on the plates are very clear. A third specimen in this collection, 16,311, also from Coplaw, consists of interambulacral plates with spines and pyramids of the lantern.

The pyramid is wide-angled with a moderately deep foramen magnum. A half-pyramid seen from within shows the dental slide not quite reaching to the base of the foramen, the usual Palaeozoic character. The pyramids show the suture for the epiphyses, but these structures are wanting. The longest spine measures 12 mm. in length. This specimen is the most instructive for the lantern of any known in this species. The specimen from Hook Head in the Museum of Practical Geology Collection 16,315, is a crushed test seen from the dorsal side. It shows two genital plates which are wide, rather low, and each has five genital pores.

In the British Museum Collection E 10,686 to 10,688, there are three specimens of this species from Yorkshire. The specimens consist of small slabs with interambulacral plates bearing eccentric primary and secondary tubercles. There are fragments of spines, but no ambulacral plates; one of the specimens, E 10,686, has two half-pyramids similar to those of *Lepidesthes*. One of these as seen from side view shows ridges for the attachment of interpyramidal muscles.

Mr. Hawkins's specimen, which he collected at Clitheroe, consists of dissociated interambulacral plates, a few ambulacrals, and a very good half-pyramid, which has ridges for the attachment of interpyramidal muscles.

All of the English specimens seen are clearly referable to the genus. The plates are thicker and more massive than in the Irish specimens, so that they may represent a distinct species. In their very fragmentary condition it is best to leave them in *biserialis*.

***Perischodomus illinoisensis* Worthen and Miller.**

Text-fig. 247.

Perischodomus illinoisensis Worthen and Miller, 1883, p. 333, Plate 31, fig. 8; Klem, 1904, p. 20; Lambert and Thiéry, 1910, p. 122.

Perischodomus (?) *illinoisensis* Keyes, 1895, p. 191.

Tretechinus illinoisensis Tornquist, 1897, p. 784.

TEXT-FIG. 247.—*Perischodomus illinoisensis* Worthen and Miller. Chester Limestone, Lower Carboniferous, Bay City, Pope County, Illinois. Holotype, dorsal view, natural size (after Worthen and Miller, 1883, Plate 31, fig. 8).

I have not seen specimens of this species, and the characters are taken from the original description. Ambulacra are narrow, with two columns of low, interlocking plates, with a pore-pair in each plate. Ambulacral plates not uniform in size or shape, though most of them seem to have an imperfectly pentagonal outline. The ambulacral plates imbricate adorally. The interambulacra have five, or perhaps seven columns of plates in an area. The plates are very irregular in size, imbricating aborally and probably from the center outward; at least the adradial plates imbricate laterally over the ambulacra. The plates bore two kinds of spines. The primary tubercle is moderately large, perforate. There is only one plate with a primary tubercle seen, and that

is in one of the median columns. Secondary tubercles on adradial plates and perhaps [probably] on others.

Chester Limestone, Lower Carboniferous, Bay City, Pope County, Illinois. The type as stated by Worthen and Miller is in the Illinois State Collection no. 2,483. This species is imperfectly known. The fact that it has two columns of ambulacral plates, and primary and secondary tubercles on interambulacral plates, with other characters, seems quite sufficient to refer it to *Perischodomus*.

PERISCHOCIDARIS Neumayr.

Archaeocidaris (pars) Baily, 1874, p. 42; (pars) 1875, p. lxviii.

Perischocidaris Neumayr, 1881, p. 174; Lambert and Thiéry, 1910, p. 126.

Prosechinus Pomel, 1883, p. 113.

Homotocchus Sollas, 1892, p. 153.

Perischodomus (pars) Duncan, 1889a, p. 10; (pars) Klem, 1904, p. 19.

Test spheroidal. Ambulacra broad with six columns of plates at the mid-zone, composed of wide occluded, narrower demi-, and one column of isolated plates in each half-area (Plate 67, fig. 1). The two median columns of occluded plates in the middle line of each area are elevated in rounded ridges similar to those of *Melonechinus*. Pore-pairs are in sunken valleys, in three vertical series on either side, and lie in the outer portion of the ambulacral plates in each half-area.

The interambulacra are wide with in each area five columns of plates at the mid-zone, the plates are high, convex, polygonal, and rounded on the suture lines. Part of the interambulacral plates bear large, elevated, perforate primary tubercles with secondary tubercles, which latter exist on all coronal plates as shown by Baily (1874).

The oculars are small, insert, and imperforate, ventrally covering the ambulacra and laterally in part the interambulacra on either side. The genitals are high, wide, and peculiar in that most of them bear a large primary tubercle. Genitals have from three to six pores each. One of the genitals does not show any pores (Plate 67, fig. 3), but this is ascribed simply to imperfection of the mold, as the only known specimen is an external sandstone mold. This same imperforate plate is also without a primary tubercle which exists on the four other genitals, but I see no necessary reason for considering it a madreporite as does Sollas. There are no genitals with sixteen pores, as stated by Harte (1865, p. 68) and Neumayr (1881). The ventral half of the test is unknown.

This genus differs from the *Palaecechiniidae* in having large perforate primary tubercles on interambulacral plates, also in that the plates are probably imbricate. It differs from other genera of the *Lepidesthidae* in having melon-like ribs in the ambulacra. It is the first genus of the family systematically considered which has more than two columns of plates in an ambulacral area.

Type and only known species, *Perischocidaris harteiana* (Baily) from the Lower Carboniferous of Ireland.

***Perischocidaris harteiana** (Baily).

Plate 65, figs. 1, 2; Plate 67, figs. 1-3.

— (without name) Harte, 1865, pp. 67-69 and 90, Plate 5, three figs.

Archaeocidaris sp. Baily, 1865c, p. 90.*Archaeocidaris harteiana* Baily, 1874, p. 42, Plate 4, figs. a-c; 1875, p. lxviii.*Perischocidaris hartei* Neumayr, 1881, p. 175, Plate 1, fig. 7; Lambert and Thiéry, 1910, p. 126.*Prosechinus harteiniana* Pomel, 1883, pp. 113, 114, Plate [no number], fig. 35.*Homotoechus hartii* Sollas, 1892, p. 153.*Perischodomus hartei* Klem, 1904, p. 19.

This species is known only from external sandstone molds of the dorsal side of two tests (Plate 65, fig. 1). One of these is nearly complete, the other is a small fragment only. These specimens on a single slab are in Trinity College, Dublin, where I studied them through the kindness of Professor John Joly. A cast is in the Sedgwick Museum, Cambridge, England, 13. The mold of the more complete specimen (Plate 65, fig. 1) is a cup-shaped cavity, a plaster cast of which is shown in Plate 65, fig. 2. These indicate a spheroidal test, although the ventral half is unknown. The diameter of the test is about 75 mm. The ambulacra at the mid-zone are about 12 mm., the interambulacra about 35 mm. in width.

The ambulacra at the mid-zone have six columns of ambulacral plates composed of wide ocluded, narrow demi-, and one column of isolated plates in each half-area (Plate 67, fig. 1). The plates of the two ocluded columns are elevated in a high, rounded melon-like rib that suggests the character in *Melonechinus* (compare Plate 54, fig. 1), a feature not known in any other species of the family, although the whole ambulacrum is rounded outward in a rib-like fashion in *Lepidesthes carinata* (Plate 66, fig. 11). The pore-pairs lie in depressed valleys on either side of the ambulacra and are situated near the outer border of each ambulacral plate. A peripodium around each pore-pair is figured by Harte and better by Baily (1874), but I overlooked it in my somewhat hurried examination of the specimen. Baily figures a small tubercle on the inner part of each ocluded plate. About four ambulacral plates equal the height of an adambulacral, as Harte observed.

The interambulacra are broad, with five columns of plates in each area in the zone of the most adoral portion preserved, which I take it is about on the plane of the mid-zone (Plate 65, fig. 1). Dorsally, part of these columns drop out before reaching the apical disc. As shown in Plate 67, fig. 2, column 5 drops out first, then 4, and finally 3, columns 1 and 2 alone reaching the apical disc, and the youngest plates lying in contact with the two oculars on either side. This is the most extreme reduction of columns seen in any member of the Perischoechinoida (p. 211). The interambulacral plates are high and rounded outwardly, being more strongly convex to the exterior than in any sea-urchin that I know. The plates are polygonal, but

rounded on the suture lines, which I think indicates that the plates were more or less imbricating, a family character. However, as the plates are represented only by external molds, it is difficult to be certain on this point. Adambulacral plates are pentagonal, median plates hexagonal or an equivalent of the same. Part, but not all, of the adambulacral plates bear a large, elevated, perforate primary tubercle which is the largest known in the family, and is surpassed in size in the Palaeozoic only by the Archaeocidaridae. A large tubercle is on the second and fourth adambulacral plates from the apical disc (Plate 67, fig. 2), and this peculiar system seems to hold for each area, as pointed out by Harte and by Bailly (1874). The latter also shows numerous secondary tubercles scattered over all the interambulacral plates, and, according to his figures there are primary tubercles on some additional adambulacral plates, also on a few plates of the median columns.

The apical disc is in place complete (Plate 67, fig. 3). The oculars are small and imperforate, and all separate the genitals, meeting the periproct as in *Melonechinus*, etc. Ventrally, they cover the ambulacra and laterally the interambulacra in part on either side. The genitals are high and wide, almost V-shaped on their adoral termination. Four of the genitals have a prominent primary tubercle, but it is wanting in one, very likely from imperfection of the mold. This is the only case of large primary tubercles on genital plates known in the Palaeozoic, and it is exceptional in any Echini. None of the genitals has sixteen pores, the number given by Harte and Neumayr. Bailly pointed out this error and said that there were six pores in four of the genitals arranged in a semicircle, ventral to the large tubercle. In my observations I found six pores in genital C (Plate 67, fig. 3), five pores in genitals A and I, and only three pores in genital G. In genital E no pores were seen, but this may fairly be ascribed to imperfection of the sandstone mold, not to any structural difference of this plate. A similar apparent absence of pores is seen in several genital plates in Plate 53, fig. 1. Harte and Sollas consider the genital without primary tubercle or pores as a madreporite. This may be correct, but in the absence of madreporic pores, which are very rare in the Palaeozoic (p. 172), this view must be taken with qualification.

This is one of the most distinct species of Palaeozoic Echini, making no close approach to any other known form. It is from the Lower Carboniferous, yellowish sandstone, Lough Esk, about six miles from Donegal, Ireland. This important and unique specimen is in the collection of Trinity College, Dublin.

PROTEROCIDARIS Koninek (emended).

Proterocidaris Koninek, 1881, p. 514, Plate 8.

Oligoporus (pars) Lambert and Thiéry, 1910, p. 121.

In describing this genus, de Koninek did not give the characters of the ambulacrum, but his figure of the type and only known species, *Proterocidaris giganteus* de Koninek, bears a close

resemblance to the sea-urchins figured by Fraipont (1904) as *Oligoporus soreili* sp. nov. Fraipont's specimens, as well as de Koninck's, are from the Carboniferous of Belgium, and on the evidence it seems to me that *Oligoporus soreili* is a synonym of *Proterocidaris giganteus*. Acting on this opinion, the characters of the genus *Proterocidaris* are emended by features gathered from Fraipont's publication.

Test large, spheroidal, or flattened. The ambulacra are narrow, composed at the mid-zone in each area of four columns of low plates which evidently imbricate adorally and laterally bevel under the adradials. Interambulacra are broad, with many columns of plates at the mid-zone. (According to de Koninck's description, there appear to be 65 columns as a whole, and in Fraipont's figures there are from twelve to thirteen columns in each interambulacral area.) The interambulacral plates imbricate strongly aborally and from the center laterally and over the ambulacra on the adradial sutures. The interambulacral plates bear each a small primary with secondary tubercles and corresponding spines (Plate 65, fig. 3). The apical disc is known only from one genital plate (Fraipont, 1904, Plate 5, fig. 1), which is low and wide. The peristome, periproct, and lantern are unknown. This genus differs from any of the Palaeoecchinidae by its imbricating plates and also by its primary tubercles and spines. It differs from other genera of the Lepidesthidae by its four columns of ambulacral plates. It has also many more columns of interambulacral plates than are known in other genera of this family.

Type and only known species, *Proterocidaris giganteus* from the Lower Carboniferous of Belgium.

***Proterocidaris giganteus* Koninck (emended).**

Plate 65, fig. 3; Plate 67, figs. 4-7.

Proterocidaris giganteus Koninck, 1881, p. 514, Plate 8; Klem, 1904, p. 74.

Oligoporus soreili Fraipont, 1904, p. 10, Plate 3, fig. 2; Plate 4, figs. 1, 2; Plate 5, figs. 1, 2.

Oligoporus giganteus Lambert and Thiéry, 1910, p. 121.

This species is known from de Koninck's publication and also from the description and fine photographic figures given by Fraipont of what he calls *Oligoporus soreili* sp. nov., but which I consider a synonym as above discussed. Messrs. Lambert and Thiéry (1910), consider Fraipont's species *soreili* a synonym of de Koninck's *giganteus*, but retain the generic name *Oligoporus* for the species.

The test is apparently spheroidal, though flattened in the specimens figured. De Koninck says that the diameter of his specimen is exactly 30 centimeters, which represents certainly a huge sea-urchin. Basing additional measurements on Fraipont's Plate 4, fig. 1, which he says is natural size, the test is in this case 160 to 170 mm. in diameter. The ambulacra at the mid-zone, as represented by the periphery of the figure cited, measure about 10 mm. in width and the interambulacra about 85 mm. in width.

The ambulaera are narrow, at the mid-zone composed of four columns which consist of occluded and demi-plates in each half-area (Plate 67, fig. 5). In this figure the plates of the two half-areas are mechanically separated. It is a view from the interior, and the occluded and demi-plates, at least on this side of the test, are of about equal width, and pore-pairs lie near the middle of each half-area, doubtless due to the fact that it is an internal view (compare Plate 43, figs. 3, 4). About three ambulaeral plates equal the height of an adambulaeral, and they bevel under the adambulaerals on the adradial suture (or over them, as seen in internal view). De Koninck says that in the type the ambulaera are not visible, but, in the flattening of a form with interambulaeral plates imbricating laterally, it is mechanically natural that this area should be overridden and thus shut out from external view, as occurs in *Perischodonus biserialis* (Plate 29, fig. 5).

The interambulaera are very broad, with numerous columns of plates in each area. De Koninck says that the type appears to have 65 columns; this would be an average of thirteen columns to an area, which is just the number shown here in Plate 67, fig. 4, after Fraipont. In his description, Fraipont says that there are eleven or twelve columns of plates at the middle [mid-zone]. In a section seen from the exterior (Plate 67, fig. 4) at the mid-zone there are seen to be thirteen columns of plates. The thirteenth column originates on the left next to the adradial column. The initial plate of this column is a pentagon, and instead of having a heptagon on its ventral border as usual, the adambulaeral plate X has attained an additional compensating side, so that it is hexagonal instead of pentagonal as usual. The interambulaeral plates imbricate strongly dorsally and from the center laterally and over the ambulaerals. Each plate bears a small primary tubercle with numerous secondary tubercles. The primary spines are small, slender, and swollen at the base. De Koninck says that the primary spines have a length of 10 mm. and a diameter at the base of 1 mm. The primary spines shown in Fraipont's figures are smaller, apparently about 4 mm. long, but his specimen is much smaller than the type. The secondary spines are more slender than the primaries, and measure about 2 mm. in length, judging from the figure (Plate 67, fig. 7).

The interambulaera as seen from within are very interesting for comparison. In this internal view (Plate 65, fig. 3, area I; Plate 67, figs. 5, 6) the plates imbricate adorally and toward the center from the sides, largely covering up the median column of the area; also the ambulaeral plates laterally bevel over the adambulaerals. All this is just the reverse of what is seen on the exterior, as shown in different areas of Plate 65, fig. 3 (also compare text-figs. 32 to 35, p. 75). Fraipont's fig. 2 on Plate 5 is inverted; that is, the dorsal portion is toward the bottom of the plate. This gives the impression that the direction of imbrication is the reverse of what it really is, but I have corrected the orientation in my copy of part of this figure (Plate 67, fig. 5). In the specimen figured on Plate 65, fig. 3, there are twelve columns of plates in interambulaerum I, and in the view of a section from another specimen (Plate 67, fig. 5) there are twelve columns. In one of Fraipont's figures (his Plate 5, fig. 1) there is a low, wide genital

surmounting the interambulacrum. The pores cannot be distinguished in the photographic figure. This is all that is known of the apical disc in this species.

Professor Fraipont says that he had twelve specimens, so that it is evidently quite abundant where found. He referred his specimens to the genus *Oligoporus*, comparing the ambulacrum with that of my *Oligoporus* (= *Lovenechinus*) *missouriensis*, see text-fig. 244, p. 338, of this memoir. Structurally, as regards this character, the comparison is apt, but other characters, as imbrication of plates and two kinds of tubercles and spines, remove this species from *Oligoporus* or *Lovenechinus*, and all other genera of the Palaeochinidae as well. The characters are very distinctive and do not fit into any known genus of Palaeozoic Echini except *Proterocidaris*, as discussed under consideration of the genus.

De Koninck's type specimen is from the Lower Carboniferous of Lovers, Belgium. Fraipont's specimens are from the Lower Carboniferous, Marbre Noir, of Dinant, Belgium.

LEPIDESTHES Meek and Worthen.

Lepidesthes Meek and Worthen, 1868a, p. 522; Lovén, 1874, p. 42; Duncan, 1889a, p. 16; Jackson, 1896, p. 241; Tornquist, 1897, p. 732; Klem, 1904, p. 24; Lambert and Thiéry, 1910, p. 123.

Lepidesthes Neumayr, 1881, p. 151.

Hybochinus Worthen and Miller, 1883, p. 331; Duncan, 1889a, pp. 16-18; Tornquist, 1897, p. 732.

Test spheroidal, elliptical, or obovate, exceptionally with elevated rounded ribs (*L. carinata*). Ambulacra very wide at the mid-zone, with in each area from eight to sixteen columns of plates, which consist of occluded plates that meet the middle of the area, demi-plates that meet the interambulacra laterally, and, in addition, from two to six regular columns of isolated plates in each half-area. Ambulacral plates are all small, uniform in size, and rhombic or hexagonal in shape (Plate 70, figs. 1-3), imbricating adorally, and laterally beveled strongly under the adambulacrals. Pore-pairs are in peripodia, situated in each plate above the middle, and in the middle line or more typically nearer the next adjacent interambulacrum than the middle of the plate. Ambulacral plates bear many secondary tubercles and spines but no primaries (Plate 67, figs. 8, 10). As seen from the interior of the test, ambulacral plates imbricate aborally and bevel over the adradials laterally, and pore-pairs are about in the middle of each plate. For comparison of imbrication seen from the exterior and interior, see text-figs. 32 to 38, p. 75, where these relations are shown. Ventrally, near the peristomal border there are four columns of ambulacral plates as a stage in development (Plate 68, fig. 3), above which area the number of columns increases to the full number at the mid-zone. Dorsally, as a localized stage in development, there is a very simple condition of the ambulacrum next to the ocular plates (Plate 68, fig. 5; text-fig. 251, p. 428), and from this area passing ventrally toward the mid-zone the number of columns increases to the full specific number.

The interambulacra are very narrow at or near the mid-zone with in each area from three to six columns of small plates of uniform size that imbricate strongly aborally and from

the center outward and over the ambulacra on the adradial sutures. These plates are strongly rounded in outline, and on the exterior bear numerous secondary tubercles with corresponding spines (Plate 67, figs. 8, 13, 14). There are no primary tubercles or primary spines known in the genus. The interambulacral plates as seen from the interior imbricate adorally and from the sides toward the center; and laterally bevel under the ambulacra, just the reverse of the exterior. On the interior also the plates are much less rounded and more sharply angular than on the exterior, all as shown diagrammatically in text-figs. 32 to 38, p. 75. The primordial interambulacral plates are in place in the basicoronal row (Plate 68, fig. 3), and, as far as known, there are two plates in the second row, three in the third, and four in the fourth as usual in the *Perischoechinoida*. In later growth a fifth and a sixth column may develop dorsally, as in Plate 66, fig. 10, or one of the four ventral columns may drop out so that for most of the area there are only three columns, as in Plate 67, fig. 8.

The peristome is covered with ambulacral plates only (Plate 68, fig. 3). The apical disc is small proportionately to the diameter of the test, and is rather fully known, oculars are inserted, separating the genitals, and with two pores each (Plate 68, fig. 5), which latter is a very unusual character (p. 81) and perhaps represents an individual variant. Or the oculars may be apparently quite imperforate (text-fig. 251, p. 428). The genitals are low and wide, with two or three pores each. In some cases no pores are visible, but this is ascribed to preservation and not to a real absence of pores. A madreporite with typical fine pores occurs in two known cases (Plate 68, fig. 5; Plate 71, fig. 1). The periproct is plated with many small, somewhat rounded plates, which are less angular than in the *Palaeoechinidae* (Plate 68, fig. 5; text-fig. 251, p. 428). The lantern is inclined, teeth are grooved, pyramids wide-angled, with a moderately deep foramen magnum, and laterally with ridges for the attachment of interpyramidal muscles. Epiphyses are narrow, capping the half-pyramids. The brace is of the character typical of all regular *Echini* (Plate 68, figs. 9-14).

Mr. Agassiz (1881, p. 79) in discussing the *Echinothuriidae*, says of the aetinal system (peristome) that "from the similarity of its structure in such genera as *Archaeocidaris*, *Pholidocidaris*, and *Lepidesthes*, we can fairly assume that the abactinal system [oculo-genital plates] corresponds in its general features with that of the *Echinothuriidae*." I think that this statement is hardly justifiable. In the *Perischoechinoida* there is no evidence of gill cuts for peristomal gills (p. 223), whereas these are present in the *Echinothuriidae*.¹ In *Archaeocidaris* there

¹ Mr. Agassiz (1874, p. 645) says, "It is well known that the *Cidaridae* and *Echinothuriidae* have no cuts in the test for the passage of the aetinal gills, but we find these cuts directly at the point of contact of the buccal membrane and the teeth, and there the gills make their appearance." (See also A. Agassiz, 1874, pp. 694, 699; 1881, p. 53.) The *Cidaridae* have no external or peristomal gills, but do have internal radially situated Stewart's organs (pp. 61, 62, 212). On the other hand the *Echinothuriidae* do have small peristomal gills, which, as usual in the *Centreechinoida* (pp. 62, 213), impinge upon the basicoronal plates of the interambulacra thus making slight reentrant cuts (text-figs. 43, 44; pp. 80, 83). The *Echinothuriidae* in addition to peristomal gills have internal radially situated Stewart's organs (p. 214).

are both ambulacral and non-ambulacral plates on the peristome, while in the Echinothuriidae there are ambulacral plates only (text-figs. 43, 47, p. 80). I do not know the character of the peristome in *Pholidocidaris* (p. 433), but presume that like *Lepidesthes* (Plate 68, fig. 3) it had ambulacral plates only, and in so far both genera may be compared with the Echinothuriidae as regards the structure of the peristome. I do not see that a similarity of the peristome, where existent, necessarily implies a similarity of the apical disc, as assumed by Mr. Agassiz. The character of the apical disc in the Echinothuriidae is to have oculars all insert, genitals split by secondary sutures, and very commonly for oculars and genitals to be separated, so that the periproct comes in contact with the interambulacra (text-fig. 170, p. 149; also pp. 63, 110, 168, 213). This last feature, of separation, apparently was the most important one in Mr. Agassiz's mind. Mr. Agassiz (1904, p. 30, Plate 11, figs. 1, 5, 6) shows that in *Porocidaris cobosi* the peristome may be covered with ambulacral plates only, yet the apical disc with exsert oculars is very different from that of the Echinothuriidae (p. 110). In the apical disc of the Perischoechinoida oculars are usually all insert (p. 89); I know of no case of split genitals, and oculars and genitals form a closed ring in all cases I know of with the possible exception of *Koninckocidaris silurica* (pp. 286, 287). I do not know the structure of the apical disc in *Archaeocidaris* (pp. 265, 266), though I infer from a statement on another page of the work cited, that Mr. Agassiz (1881, p. 80) did. The apical discs in *Lepidesthes* (text-fig. 251, p. 428; Plate 68, fig. 5), and *Pholidocidaris* (Plate 73, figs. 3, 4) as far as known do not bear any close resemblance to that structure in the Echinothuriidae.

In discussing the anal system, Mr. Agassiz (1881, p. 11) says, "The figures of Bailey, and of Meek and Worthen, and a specimen of *Lepidesthes* which I have had occasion to examine, would seem to indicate a splitting up of the central plate into a great many smaller plates." Baily (1865b, Plate 4, fig. B) figured the periproctal plates of *Palaeochinus elegans* (p. 309), but I believe neither he nor any one else has shown a central (suranal) plate in Palaeozoic species (pp. 174, 176). As regards the origin of periproctal plates by splitting in *Lepidesthes* as assumed by Mr. Agassiz, I can only say that I have seen no evidence for the formation of periproctal plates by splitting in this or any other genus of Echini. It appears rather that periproctal plates originate as separate centers of calcification (text-figs. 59-170). Mr. Agassiz (1874, p. 642) says that the compound ambulacral plates of the Centrechinoida are formed by splitting, whereas they are clearly formed by the coalescence of originally simple plates as discussed (pp. 55, 56). He also considered that interambulacral plates in the Echinothuriidae are derived from the periproct and he assumed the same view for certain of the Perischoechinoida (A. Agassiz, 1881, p. 80; 1883, p. 33). As Mr. Agassiz (1883, p. 32) expresses it, "The new interambulacral plates are found to be pushing out from the plates of the anal system on each side of the genital plates." Or as he says later (A. Agassiz, 1904, p. 95), "That this remarkable intercalation exists there is not the slightest doubt, and it naturally suggests in old

specimens a flow of anal plates into the interambulacrum, similar to the flow of the ambulaeral plates of the corona onto the buccal plates of the actinal system." This view of an entirely distinct origin for interambulacral plates from what obtains in all other Echini I believe is a mistake (pp. 63, 110, 287). Mr. Agassiz (1881, p. 95; 1904, pp. 96, 104) also says that interambulacral plates in the Echinothuriidae and apparently in the Perischoechinoida are formed by the splitting up of earlier plates. I believe this view is incorrect as discussed (pp. 64, 362). Yet it is possible that coronal plates may originate by splitting, as a peculiar case of the splitting of ambulaeral plates is shown by Dr. Mortensen (1907, text-fig. 27, p. 171) in *Sperosoma grimaldi* Koehler. This case was overlooked in my discussion of the origin of plates by splitting (p. 28). In *Sperosoma* the primary element of each compound ambulaeral plate in passing adorally in development becomes divided by a vertical secondary suture, so that as a result there exist two admedian columns of imperforate ambulaeral plates. I know of no other similar case in coronal plates, and Messrs. Agassiz and Clark (1909, p. 194) say of this genus, "The existence of a pair of median columns of imperforate ambulaeral plates is a feature in which *Sperosoma* is absolutely unique among all recent regular Echini." I believe the case of *Sperosoma* and the splitting of genitals and rarely of oculars as discussed (pp. 28, 168-170), are the only cases in Echini in which plates have been shown to be derived by the splitting of preëxistent plates.

The type species is *Lepidesthes coreyi* Meek and Worthen, from the Lower Carboniferous of America. This genus is striking on account of the great development of the ambulaera (compare text-figs. 2-14, p. 54) and the relative reduction of the interambulacra. In ambulaeral differentiation it is surpassed only by the new genus *Meekechinus*. The geologically oldest species of *Lepidesthes* occurs in the Devonian of England, and the geologically highest, also the structurally highest species, is found in the Coal Measures of North America.

Key to the Species of Lepidesthes.

Eight columns of plates in each ambulaeral area and three columns of plates in each interambulacral area at the mid-zone *L. wortheni* Jackson, p. 416.

Probably eight or more columns of plates in an ambulaeral area, with four known columns of plates in an interambulacral area *L. laevis* Trautschold, p. 418.

Eight columns of plates in each ambulaeral area and five columns of plates in each interambulacral area *L. formosa* Miller, p. 418.

(?) Incompletely known, apparently eight columns of plates in an ambulaeral area and seven columns of plates in an interambulacral area *L. deronicens* Whidborne, p. 420.

Ten or more columns of plates in an ambulaeral area and five columns of plates in an interambulacral area *L. spectabilis* (Worthen and Miller), p. 421.

Ten or twelve columns of plates in an ambulaeral area and six columns of plates in each interambulacral area *L. coreyi* Meek and Worthen, p. 423.

Twelve columns of plates in an ambulacral area and six columns of plates in an interambulacral area; ambulacral areas elevated as prominent ribs *L. carinata* sp. nov., p. 424.

Sixteen columns of plates in each ambulacral area and four (exceptionally five) columns of plates in each interambulacral area; ambulacra about twice as wide as the interambulacra *L. colletti* White, p. 425.

Sixteen columns of plates in an ambulacral area and four columns of plates in each interambulacral area; ambulacral areas several times as wide as the interambulacral *L. extremis* sp. nov., p. 430.

Number of columns of ambulacral and interambulacral plates in an area unknown; ambulacral plates proportionately lower and wider than in any other known species of the genus *L. caledonica* sp. nov., p. 432.

****Lepidesthes wortheni* Jackson.**

Plate 66, figs. 1-3; Plate 67, figs. 8-14.

Lepidesthes wortheni Jackson, 1896, pp. 207, 241, Plate 9, fig. 53; Klem, 1904, p. 26; Lambert and Thiéry, 1910, p. 123.

Test elliptical. The type (Plate 66, fig. 3) is a small individual and measures about 36 mm. in height and 27 mm. in width, but it is incomplete laterally, and the diameter, if complete, would be somewhat greater, probably about 30 mm. The ambulacra at the mid-zone measure 9 mm. in width and the interambulacra from 5 to 6 mm. in width. A large and nearly perfect specimen in Mr. Braun's collection (Plate 66, fig. 1) measures about 60 mm. in height and 55 mm. in width through the mid-zone. The ambulacra at the mid-zone measure 15 mm. in width and the interambulacra 9 mm. in width.

The ambulacra are wide, with eight columns of plates at the mid-zone. The plates are nearly or quite rhombic in young specimens (Plate 67, fig. 9), but are hexagonal in larger specimens (Plate 67, fig. 8). Ventrally, near the peristome there are four columns of plates only, in this character being like the ventral border of *Melonechinus* (Plate 56, fig. 3). The pores are surrounded by peripodia, and are situated above the middle and nearer the outer border than the median line of each plate, so that from the median line they are situated toward the next adjacent interambulacrum on either side (Plate 67, figs. 8, 10). In small specimens the pores lie nearer the middle line of each plate (Plate 67, fig. 9). The ambulacral plates bear numerous secondary tubercles; they imbricate adorally, and laterally bevel strongly under the adradials.

The interambulacra are narrow, with, at the mid-zone, three columns of plates which are rounded on the suture lines. The plates imbricate strongly aborally, and the plates of the central column imbricate strongly laterally over the plates of the two adradial columns, and these in turn over the ambulacrals on the adradial sutures (Plate 67, fig. 8). The interambulacral plates bear numerous secondary tubercles and spines, which are slender, swollen at the base, and vertically finely striate (Plate 67, figs. 13, 14). At the ventral portion of the interambulacrum, as far adorally as preserved, there is a row of three plates (Plate 67, fig. 8). Above this row a fourth column is introduced with a pentagonal plate, but there are only four

plates in this fourth column, above which three columns continue to the dorsal limit of the test (p. 374). A similar short-lived fourth column exists ventrally in other specimens of the species where this area is clearly preserved (Plate 67, fig. 9). There are only three species known in the Perischoechinoida which are characterized by three columns of plates in an interambulacrum at the mid-zone (p. 221). These are: the present species, *Melonechinus obovatus* sp. nov. (p. 374), and *Meekechinus elegans* sp. nov. (p. 444). The peristome, apical disc, and periproct are not preserved in the known specimens of this species. The lantern is inclined and pyramids are wide-angled, with a moderately deep foramen magnum. The epiphyses are narrow, capping the half-pyramids (Plate 67, fig. 12).

Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana, F. Braun Collection, one specimen; Museum of Comparative Zoölogy Collection, four specimens, nos. 3,057, 3,171, 3,172, and 3,185; Yale Museum Collection, three specimens, nos. 318, 319, and 320; F. Springer Collection, two specimens, no. 8,018. The holotype, which is in the Boston Society of Natural History Collection 11,601, was without an original label, but from the lithological character and associated fossils, it is in all probability from Crawfordsville or that vicinity.

The type as above noted is a small specimen (Plate 66, fig. 3; Plate 67, figs. 9, 12), not much more than half grown. The ambulacral plates at the mid-zone are very nearly rhombic. This is apparently an immature character as in the larger specimen (Plate 66, fig. 1), the plates at the mid-zone are hexagonal, while the younger dorsal plates are more nearly rhombic (p. 426). In the type there are only four columns of ambulacral plates ventrally, as seen in area B, and these are wider and lower than the more dorsal plates. There are three columns of plates in an interambulacral area at the mid-zone and throughout most of the area, but there are four columns of plates ventrally for a short distance in both areas A and C. This specimen on the reverse side has a well preserved pyramid with an epiphysis in place on one side (Plate 67, fig. 12). This is all that is known of the lantern in this species.

Mr. Braun's specimen (Plate 66, fig. 1; Plate 67, fig. 8) is the largest known in the species and is beautifully preserved. The ambulacral plates are wide hexagons at the mid-zone with pore-pairs set toward the next adjacent interambulacrum on either side. The interambulacral plates show the imbrication well, and in area A, where some plates are absent, the beveled edges are plainly seen. Ventrally, in area A are seen the introduction and dropping out of column 4.

The Museum of Comparative Zoölogy specimen, no. 3,171 (Plate 66, fig. 2; Plate 67, fig. 10), is less nearly complete, but is beautifully preserved. Ambulacral plates at the mid-zone are hexagonal, and the occluded plates are somewhat wider than those of other columns. The pore-pairs are in peripodia and tubercles are very plain.

Of the three Yale Museum specimens, one is very small, the youngest specimen of the species seen. Another has the spines well preserved (Plate 67, figs. 13, 14) as described above.

****Lepidesthes laevis* Trautschold.**

Plate 67, figs. 15-18; Plate 68, figs. 1, 2.

Lepidesthes laevis Trautschold, 1879, p. 8, two text-figs.

This species is known only fragmentarily; the form of the complete test is unknown. The ambulacra are wide, but the total number of ambulacral columns is unknown. There must have been, however, at least eight columns of plates, because in a fragment of an ambulacrum in the Berlin Museum (Plate 68, fig. 1) there are six columns as shown, and the right side of this is composed of hexagonal and therefore not marginal plates. To attain a marginal column and also an equal number of columns in each half-area, it is necessary to add two columns to those existent, which would give at least eight columns for the area. Ambulacral plates are thin, imbricate strongly adorally, and bevel under the adradials. They bear small secondary tubercles, and the pore-pairs are situated in the upper half of each plate (Plate 67, fig. 15; Plate 68, figs. 1, 2). On the interior of the test, the pore-pairs are in the lower half of each plate (Plate 67, fig. 16). This same character of pore-pairs in the lower half of the plates internally is seen in *Lepidesthes extremis* (p. 431; Plate 7, fig. 2).

In the interambulacra there are four columns of plates in an area, as shown by Trautschold, but his figures are inverted. The plates are thin, rounded on the suture lines, and imbricate aborally, also from the center laterally and over the ambulacra (Plate 67, figs. 15, 17, 18). On the interior the interambulacral plates are hexagonal in outline instead of rounded, as seen by comparing the outer and inner sides of the same plates in the Berlin specimen (Plate 67, figs. 15, 16). This relation of the interior and exterior of plates in this genus is also shown in text-figs. 32 to 38, p. 75.

Lower Carboniferous, Miatschkowa, Province of Moscow, Russia; this is the locality given by Trautschold for the cotypes. Moscow, Russia, two specimens in the Museum für Naturkunde, Berlin, which I studied through the kindness of Professor Jaekel.

****Lepidesthes formosa* Miller.**

Plate 66, figs. 4-7; Plate 68, figs. 3-14.

Lepidesthes formosus Miller, 1879, p. 41, Plate 8, fig. 4; Jackson, 1896, p. 210; Klem, 1904, p. 25; Lambert and Thiéry, 1910, p. 123.

Of this species I have had the opportunity to study a large series of specimens, including the types which were kindly loaned me from the Chicago University Museum by Professor Weller; also some twenty specimens in Mr. Frank Springer's collection, and two in the United States National Museum. This material not only illustrates the species, but also makes additions to the known generic characters.

Test small, spheroidal or slightly ellipsoidal. The holotype (Plate 66, figs. 4, 5), as estimated by restoring the ventral portion, measures about 33 mm. in height. The ambulacra at the mid-zone are 12 mm. in width and the interambulacra 7 mm. in width. From these measurements the circumference would be about 95 mm. and the diameter about 30 mm. This represents practically a full grown individual, none of the specimens seen being essentially, if at all, larger.

The ambulacra are wide, nearly twice as wide as the interambulacra, with, at the mid-zone, eight columns of small, nearly rhombic plates in each area (Plate 68, fig. 4). The plates imbricate adorally and laterally bevel under the adradials. The pore-pairs lie slightly above the middle of each plate, and either in the median line or a little nearer to the next adjacent interambulacrum. Ventrally, there are four columns of ambulacral plates near the peristomal border, as seen in area B of Plate 68, fig. 3. In other areas of this figure there appear to be fewer columns, but the ambulacral plates are more or less confused and the number of columns cannot be ascertained with assurance. From this zone of four columns the number increases rapidly to the full complement of eight columns, as seen in the aboral portion of ambulacrum B in this figure. Dorsally, next to the ocular plate, in the placogenous zone, there are few plates and apparently only one against the ocular, but one is such an unnatural number for an ambulacrum that there is probably some plate pushed under, or otherwise obscured. From this small number dorsally, the number of columns increases rapidly, passing ventrally, until the full number is attained. My figures of the type (Plate 68, figs. 4, 5) are so much enlarged that I could not include the whole specimen, but this is compensated for by the photographic figures (Plate 66, figs. 4, 5) and by Miller's excellent figure of the whole specimen.

The interambulacra are narrow at the mid-zone, with in each area five columns of plates which are small, rounded on the suture line, and imbricate strongly aborally and from the center outward and over the ambulacrals. Ventrally the primordial interambulacral plate is apparently in the basicoronal row (Plate 68, fig. 3), with two plates in the second row, three in the third, and four in the fourth row. The point of origin of the fifth column was not definitely ascertained, but it is below the mid-zone, and in the type (Plate 66, fig. 4) there are five columns as far ventrally as the area can be traced. Dorsally the interambulacral plates impinge upon the oculars broadly on either side.

The peristome is covered with ambulacral plates only (Plate 68, fig. 3), and this figure represents the best peristomal area known in the family. Teeth are visible in the center of the area. Dorsally in the type, a number of ocular and genital plates are in place (Plate 68, fig. 5). The oculars are relatively large and separate the genitals, meeting the periproct, as usual in the Palaeozoic. Two of the oculars have two pores. This is a very exceptional fact, as pores in ocular plates are very rare in Palaeozoic Echini, and no other case of two pores is definitely known (pp. 89, 413, 435). It is true that Bailly described two pores in ocular plates of

Palaeochinus elegans, but a further examination of his specimen convinced me that his observation was a mistake, and that the plates are imperforate, as earlier discussed (pp. 309, 363). An accidental pit due to weathering can easily be confused with a structural pore; but there seems no reason for believing that these supposed ocular pores are other than what they appear. The oculars adorally cover the ambulacra and laterally the interambulacra quite widely on either side. The genitals are wide, and almost square in shape, not produced ventrally in an elongate apex as usual in the Palaeochinidae. There are two or three pores to a genital plate, and one of the plates has clearly marked fine madreporic pores, this being one of the few cases in which this structure has been seen in Palaeozoic species (p. 172). On account of the presence of the madreporite, the figures (Plate 66, figs. 4, 5; Plate 68, figs. 4, 5) are oriented correctly by the Lovén method, which usually cannot be applied because the true axes are not known. The periproct is covered with many small plates, which are more rounded in outline than in the Palaeochinidae, but are similar to the same plates in *Lepidesthes colletti* (text-fig. 251, p. 428).

The lantern is quite fully known, more so than in any other species of the genus (Plate 68, figs. 9-14). The lantern is inclined as usual in the Palaeozoic. The pyramids are wide-angled, with a moderately deep foramen magnum; the lateral wings of the pyramids have plicate ridges for the attachment of interpyramidal muscles. The teeth are grooved (Plate 68, fig. 9). The epiphyses are narrow, capping the half-pyramids, and laterally have a glenoid cavity and tubercles for interlocking with the brace as in modern regular Echini. The brace is a block-shaped plate with condyles that fit into the glenoid cavities of the epiphyses (Plate 68, figs. 12-14), as in all regular Echini, living and fossil (p. 181).

Kaskaskia Group, Lower Carboniferous, Pulaski County, Kentucky, holotype and paratype, University of Chicago Collection 6,604; F. Springer Collection 8,042 and other specimens; Sloan's Valley, Pulaski County, Kentucky, F. Springer Collection 8,023, 8,027, 8,033, 8,043, and other specimens; United States National Museum Collection 42,349; Chester Group, Lower Carboniferous, Huntsville, Alabama, United States National Museum Collection 37,716.

****Lepidesthes devonians* Whidborne.**

Plate 68, figs. 15-17.

Lepidesthes (?) *devonians* Whidborne, 1896, p. 376; 1898, p. 200, Plate 24, figs. 1, 2; Plate 25, figs. 3a-3f.
Lepidesthes devonians Lambert and Thiéry, 1910, p. 123.

Test very large, form unknown. Whidborne estimated that it was three inches or more in diameter. The specimens in the Museum of Practical Geology consist of two slabs which are counterparts and bear the impressions of plates. One of the specimens, no. 7,160, is a mold of the interior, and the other, no. 7,161, is a mold of the exterior, and bears impressions of tub-

ercles and spines. The details of structure can be ascertained only with difficulty and not with entire certainty.

Ambulacral plates are small, about 3 mm. in width, and somewhat wider than high. They are polygonal, imbricating, with, on the exterior, pore-pairs situated in about the middle of each plate. On the internal mold they are situated somewhat nearer the ventral border of the plates (as in *Lepidesthes extremis*, Plate 71, fig. 2). The ambulacral plates bear small tubercles similar to those of the interambulacral plates. It is difficult to be certain of the number, but there are at least eight columns of ambulacral plates in an area.

In the interambulacra there are apparently seven columns in an area, as stated by Whidborne, and I confirmed this by observation. The plates are small, about 3 mm. in width and height, and bear numerous small tubercles. Whidborne says these are minutely perforate. This is doubtful, though in some of the impressions there seem to be traces of the impression of a perforation. Such are not known otherwise in the genus.

The spines are numerous, acicular, swollen at the base, and measure up to 5 mm. in length. The spines as far as seen are all essentially similar, and I saw no second series of smaller spines as Whidborne thought. Of course, in any specimen some spines are smaller than others, but I think that here there is no indication of two series as regards size. The impressions of a stout lantern are present.

Whidborne gives a very detailed discussion of this species, and, as he says, it fails to meet entirely the requirements of the genus. The main difference is the apparently minutely perforate tubercles. It does have characters of *Lepidesthes* and would not fit in any other genus, so that it seems best to leave it here. The chief interest in the species is that it is from the Devonian, and is thus geologically older than any other known species of the genus, and also it is from Great Britain, being the first of the genus described from that country. The specimen in general appearance resembles my figure of *L. extremis*, at least the internal mold does.

Pilton Beds, Upper Devonian, North Devon, England, holotype, Museum of Practical Geology Collection 7,160 and 7,161 (these being counterparts); and Croyde, England, in Mr. Whidborne's collection.

***Lepidesthes spectabilis* (Worthen and Miller).**

Text-figs. 248-250.

Hyboechinus spectabilis Worthen and Miller, 1883, p. 332, Plate 31, figs. 5a-5d, 6, 7.

Hyboechinus (without giving specific name) Duncan, 1889a, pp. 16-18.

Lepidesthes spectabilis Keyes, 1895, p. 184; Klem, 1904, p. 26; Lambert and Thiéry, 1910, p. 123.

Hyboechinus spectabilis Jackson, 1896, p. 207.

This species I have not seen, and its characters are somewhat ambiguous, as gathered from the description and figures. In regard to the imbrication in this species, Worthen and Miller

say that the ambulacra imbricate aborally and the interambulacra adorally. The imbrication of plates is shown in text-fig. 248, which figure, reversed from the original orientation, also shows a portion of the lantern somewhat displaced, but extending from what Worthen and Miller consider the dorsal side. Professor Duncan's (1889a, p. 16) statement, that Worthen and Miller may have seen the specimen from within, which would account for the direction of

TEXT-FIGS. 248-250.—*Lepidesthes spectabilis* (Worthen and Miller). Chester Limestone, Lower Carboniferous, Prairie du Long Creek, Monroe County, Illinois; cotype (after Worthen and Miller, 1883, Plate 31, figs. 5a, 5b, 5c).

248. Whole test, distorted, a horn-like protuberance extends from one side, lantern protruding; the orientation is reversed from that given by Worthen and Miller. Natural size.

249. Fragment of test, enlarged $\times 2$.

250. Horn-like protuberance, magnified.

imbrication as given, is wide of the mark, because their figure is evidently an external view. It is perfectly obvious from their figure that Worthen and Miller oriented their specimen incorrectly and that the ambulacra imbricate adorally and the interambulacra aborally as usual in Echini (p. 76). As regards the peculiar protuberances, one of which is described as "horn-like" by Worthen and Miller, they may well be considered as extreme local distortions, and the "horn-like" protuberance even as a foreign adherent body. In its length, lateral position, and structure as shown, it appears to have no relation to anything known in other Echini. Professor Duncan's (1889a, p. 17) view that

these protuberances might be considered as marsupia appears to be quite untenable.

The test is subspheroidal, about 20 mm. in diameter, as gathered from the published figure. The ambulacra are wide, with ten columns of plates in an area, Worthen and Miller say that this number may be and probably is exceeded in the equatorial zone; the plates, which are rather wide hexagons, bear each a pore-pair. The ambulacral plates imbricate adorally (see above discussion). Interambulacra with five columns of plates which are small, somewhat rounded on the suture lines, but almost rhombic in outline. Only four columns of interambulacral plates exist in the enlarged fragment (text-fig. 249). The interambulacral plates imbricate aborally (see above discussion). The surface of the plates as described is covered with small granules for the attachment of spines. Jaws are present. They are shown poorly in text-fig. 248, and better in Worthen and Miller's Plate 31, figs. 6, 7, the latter figure being doubtfully referred to this species by the authors.

Chester Limestone, Lower Carboniferous, Prairie du Long Creek, Monroe City, Illinois; same horizon, Pope County, Illinois. Worthen and Miller list the original specimen or specimens as in the Illinois State Collection, no. 2,481.

****Lepidesthes coreyi* Meek and Worthen.**

Plate 66, figs. 8-10; Plate 68, figs. 18-22.

Lepidesthes coreyi Meek and Worthen, 1868a, p. 524, text-fig. A on p. 525; 1873, Plate 16, figs. 2a, 2b; A. Agassiz, 1874, pp. 648, 649, text-fig. 4; Trautschold, 1879, p. 9; Keyes, 1895, p. 184; Jackson, 1896, p. 209; Klem, 1904, p. 25; Lambert and Thiéry, 1910, p. 123.

Lepidesthes corveyi (by clerical error) Trautschold, 1879, pp. 8, 9.

This species is known from several well preserved specimens, including the type. Test obovate, with ambitus dorsal to the mid-zone, a very unusual character in Echini (p. 32). The holotype (Plate 66, figs. 9, 10) is imperfect dorsally, but the estimated height is about 45 mm. The width is 51 mm., but this is exaggerated, due to lateral compression. The ambulacra at the mid-zone measure 12 to 13 mm. in width and the interambulacra 8.5 to 9 mm. in width. Mr. Braun's specimen (Plate 66, fig. 8) measures 57 mm. in height and 55 mm. in width at the ambitus, but this measurement as in the type is affected by lateral compression; the ambulacra measure 17 mm. in width and the interambulacra 10 to 11 mm. in width. Several other specimens measured give about the same proportionate measurements.

The ambulacra are wide, with, in each area at the mid-zone (Plate 68, fig. 18), ten or exceptionally twelve columns of plates, which are rather low, wide hexagons, bearing pore-pairs slightly above the center of each plate and also a little nearer the next adjacent interambulacrum than the middle line of each plate.

The interambulacra are narrower than the ambulacra, with six columns of plates in an area at or above the mid-zone. Meek and Worthen speak of there being six or seven columns of interambulacral plates, but I have not observed a seventh in any specimen of this species. The plates are rounded on the suture lines, and imbricate strongly aborally and from the center outward and over the ambulacrals on the adradial sutures. In the Freiburg i. B. specimen, the primordial interambulacral plate is in place in the basicoronal row. There are two plates in the second row and three in the third row, the fourth, fifth, and sixth columns coming in later, at intervals, and the sixth originating usually above the mid-zone. In the type, however, (Plate 66, fig. 10), the sixth column in area A originates below the mid-zone. Ambulacral and interambulacral plates alike bear small secondary tubercles and spines about 1 mm. in length (Plate 68, figs. 19-21). The peristome, apical disc, and periproct are unknown in this species. In the Freiburg specimen there are five dental pyramids in place (Plate 68, fig. 22), similar to those of *Lepidesthes formosa*. This species is the type of the genus.

Kcokuk Group, Lower Carboniferous, Crawfordsville, Indiana, University of Michigan Collection, holotype, no. 149; and another larger specimen, no. 150 of the same collection; F. Braun Collection; Museum of Comparative Zoölogy Collection, two specimens, nos. 3,173,

and 3,174 (from R. T. J. Coll.); Yale University Museum Collection 317; Freiburg i. B., Germany, Museum, one specimen.

The holotype in the Michigan Museum has the original label in Meek's handwriting. It is imperfect dorsally but otherwise well preserved, and is well represented in Professor Meek's figure here reproduced as Plate 66, fig. 10. There are ten columns of plates in ambulacral area B, and in interambulacrum A the introduction of the sixth column is seen just below the mid-zone. On the reverse side the tips of a strong lantern are in place. There is also a second specimen of this species in the University of Michigan Collection 150, which I studied through the kindness of Dr. A. G. Ruthven. The second specimen is much larger than the type, measuring 60 mm. in height. In one ambulacral area it has twelve columns of plates and six columns in two interambulacral areas.

Mr. Braun's (Plate 66, fig. 8) is the finest specimen of the species seen. It has ten columns of plates in an ambulacral area and six columns of plates in two interambulacral areas. At the zone represented by the figure (Plate 68, fig. 18) only five interambulacral columns were visible. This specimen has numerous secondary tubercles on ambulacral and interambulacral plates and spines about 1 mm. in length.

In the University Museum at Freiburg in Breisgau, there is an excellent specimen of this species, which I studied through the kindness of Professor Georg Boehm. It is large, about 60 mm. high, and there are ten columns of ambulacral plates in an area. Ventrally, in one interambulacrum the primordial interambulacral plate is in the basicoronal row, and additional columns come in as above described; also parts of a lantern occur as above described.

****Lepidesthes carinata* sp. nov.**

Plate 66, fig. 11.

This species is known from one specimen only, which is worn, so that details are not very clear. The test is large, with strongly elevated ambulacral areas recalling the melon-like ribs of *Melonechinus*, but here the whole area is involved instead of mainly the two median columns of occluded plates as in that genus (Plate 60, fig. 3). This species and *Perischocidaris harteiana* (p. 408; Plate 65, fig. 1) are the only members of the Lepidesthidae in which melon-like ribs have been observed. The diameter of the test is about 65 mm.; the ambulacrum is about 25 mm. wide, and interambulacrum about 11 mm. in width.

There are twelve columns of plates in an ambulacral area and six columns of plates in an interambulacral area at the mid-zone. This species is structurally similar to *Lepidesthes coreyi*, but differs in the strongly elevated ambulacral areas.

Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana; holotype in Museum of Comparative Zoölogy Collection 3,175.

****Lepidesthes colletti* White.**

Text-figs. 14, p. 54; 21, p. 59; 32-38, p. 75; 251, p. 428; Plate 69, figs. 1-8; Plate 70, figs. 1-5; Plate 71, fig. 1.

Lepidesthes colletti White, 1878, p. 33; 1880a, p. 163, Plate 40, figs. 2a, 2b; 1882, p. 362, Plate 41, figs. 2, 3; Keyes, 1895, p. 184; Jackson, 1896, pp. 210, 241; Klem, 1904, p. 24; Lambert and Thiéry, 1910, p. 123.

This species is one of the most striking known from the Palaeozoic, and I have had the opportunity of studying twelve fine specimens, including one figured by Dr. White (1880a, Plate 40, figs. 2a, 2b) which was kindly loaned me by Professor Stuart Weller; also a fine series formerly in my collection, and now in the Museum of Comparative Zoölogy, or the British Museum, and specimens in Mr. Braun's and Mr. Springer's collections.

The test is high and elliptical. When Dr. White originally described this species in 1878, he had only a single specimen which he says was in a crushed condition, the height about 45 mm. and the diameter considerably less. In Dr. White's second paper in which this species is described, he figured a second specimen which was not the type, and is considerably smaller, as he noted. This second specimen (Plate 69, figs. 2, 3) measures about 37 mm. in height and 35 mm. in width. The ambulacra at the mid-zone measure 12 mm. in width and the interambulacra 5 mm. in width. Another specimen in the Chicago University Museum, which is larger and more nearly complete (Plate 69, fig. 4), measures 47 mm. in height and 40 mm. in width. The ambulacra at the mid-zone measure about 15 mm. in width and the interambulacra 7 mm. in width. A slightly larger specimen in the Museum of Comparative Zoölogy (Plate 69, fig. 6) is somewhat flattened, but otherwise without distortion. It measures about 51 mm. in height and 40 mm. in width at the mid-zone. The ambulacra at the mid-zone measure about 14 mm. in width and the interambulacra 7 mm. in width. A very large specimen in the Museum of Comparative Zoölogy (Plate 69, fig. 8) measures about 70 mm. in height and 65 mm. in width. The ambulacra measure about 26 mm. in width and the interambulacra 9 mm. in width. These measurements show that the ambulacra are twice as wide as the interambulacra or wider, and are proportionately wider in large specimens than in smaller ones. They are, however, certainly never five or six times as wide, as stated by Dr. White (1880a, p. 163).

The ambulacra are very wide, at the mid-zone composed of 16 columns of plates. In no case have I found 18 or 20 columns in an area, as Dr. White thought possible. The structure consists of a column of ocluded plates extending from the middle of the area outward, a column of demi-plates extending from the interambulacra inward, and six regular columns of isolated plates in each half-area. This is as highly evolved an ambulacral structure as is known in any Palaeozoic sea-urchin excepting *Meekchinus elegans*, in which there are 20 columns in an area at the mid-zone (Plate 76, fig. 1). The ambulacral plates imbricate strongly adorally and

laterally bevel under the adradial plates. In the smaller specimens the plates are rhombic in outline (Plate 69, figs. 1-6; Plate 70, fig. 1; Plate 71, fig. 1), the individual plates being not at all or very slightly truncated by the succeeding dorsal or ventral plate of their own vertical series. As a result, the plates appear to lie in diagonal series instead of in the usual vertical series. In large specimens, however, the plates by horizontal growth have taken on a hexagonal form in which the dorsal and ventral borders truncate or are truncated by the next succeeding dorsal or ventral plates of their own vertical series (Plate 69, figs. 7, 8; Plate 70, fig. 3). It is to be observed that a specimen, as Plate 69, fig. 8, in which the plates are hexagonal at the mid-zone, dorsally has rhombic plates, these younger plates as a localized character being like the rhombic plates at the mid-zone in a younger individual. This is the same relative structure as is shown in the ambulacra of *Lepidesthes wortheni* (p. 417). The pore-pairs in each plate lie in the dorsal half, as shown by Dr. White, and when the plates are rhombic, lie in about the middle line; but as the plates widen to a hexagonal form, the pores come to lie nearer the next adjacent interambulacrum than the middle of the plate, as usual in Echini (text-figs. 4-14, p. 54). The ambulacral plates bear small secondary tubercles and spines similar to those of the interambulacral areas. Dorsally, next the apical disc (text-fig. 251, p. 428), there are two ambulacral plates in an area. Both of these are primaries, therefore crossing the half-area in which they lie. From this simple condition of primaries only, as a localized stage, the number of columns increases, passing ventrally to the full number characteristic of the species, and, in taking on this number, the ambulacrum passes rapidly through a series of stages or phases in which there is the same number of columns that may be found as an adult character in lower species of this genus. These dorsal localized stages in *Lepidesthes* are directly comparable to the similar stages that I have shown in several species of *Melonechinus* (text-fig. 237, p. 231; pp. 366, 380).

The interambulacra are narrow, half the width of the ambulacra, or less, and at the mid-zone consist of four columns of plates which extend ventrally and dorsally as far as the areas could be traced in the several specimens. In one area dorsally in one large specimen (Plate 69, fig. 7; Plate 70, fig. 4) a fifth column originates 14 mm. from the top. This is the only case of more than four columns seen in the species. The interambulacral plates are small, rounded on the suture lines, and imbricate strongly aborally, also from the center laterally, and over the ambulacra on the adradial sutures. In *Lepidesthes wortheni* (Plate 67, figs. 8, 11) and *L. formosa* (Plate 68, figs. 5, 6) there is an odd number of columns of interambulacral plates, and in these the middle column imbricates laterally in two directions, and the plates of this column on the exterior are therefore wider than those of the lateral columns which imbricate laterally only in one direction, to the left in the left half of the area and to the right in the right half of the area. In *Lepidesthes colletti* with four columns of plates there is obviously no middle column. In this case the plates of column 3 are usually wider, and imbricate laterally in two directions,

as in areas 1, 2, 3, and 5 of Plate 71, fig. 1; but sometimes the plates of column 4 are the wider and imbricate laterally in two directions, as in area 4 of this same figure. In a total of 27 interambulacral areas observed, column 3 has the wide plates in eighteen cases and column 4 has the wide plates in nine cases. Why there is this tendency to left-handedness in regard to which column has the wide plates, is without explanation, but it emphasizes the definiteness of arrangement in trifling details. The interambulacral plates as seen from the interior are angular, and imbricate adorally and from the sides toward the center; also the ambulacral plates in this view bevel over the ambulacrals. This relation of imbrication seen from the exterior and interior is shown diagrammatically in text-figs. 32 to 38, p. 75. Interambulacral plates, like the ambulacrals, bear small secondary tubercles and spines about 1.8 mm. in length.

The plates of the peristome are not preserved in any of the specimens, but tips of the dental pyramids and teeth are in place in two cases. The apical disc is in place in two specimens (Plate 69, figs. 1, 5; Plate 71, fig. 1; text-fig. 251). In the larger of these specimens (Plate 69, fig. 1) the apical disc measures about 6 mm. in diameter and the specimen about 37 mm. in diameter. The apical disc is therefore relatively small, being proportionately about 16 % of the diameter of the test. A small apical disc is a progressive character (p. 87) and is in keeping with the great development of the ambulacrum which marks this species as a highly specialized type amongst Echini. The oculars are rounded plates, lying above the ambulacral areas and covering the interambulacra in part on either side, seen clearest in areas I and V (text-fig. 251). The genitals are wide, rounded plates. Genital 1, which is partially hidden, shows two pores, and genital 5 has three pores. Genital 2 shows numerous clear, fine madreporic pores, and by this structure the specimen was oriented by the Lovén method. Rather curiously the madreporite does not show any genital pores. Genitals 3 and 4 are in part hidden and do not show any pores. The plates of the periproct are numerous, small, rounded, similar to those of *Lepidesthes formosa* (pp. 413, 419).

Keokuk Group, Lower Carboniferous, Salem, Washington County, Indiana. This is the locality of Dr. White's holotype, the only one he had when first publishing the species. I do not know where the specimen is; the specimen from the same locality, of which he published a figure in his second paper on this species (1880a), is in the University of Chicago Collection 6,340. The location of the specimen which Dr. White figured in his third paper (1882) I do not know. The same horizon, Bono, Indiana, University of Chicago Collection 6,641; Bono, Lawrence County, Indiana, two fine specimens, Museum of Comparative Zoölogy Collection 3,183, 3,184; Montgomery County, Indiana, Museum of Comparative Zoölogy Collection 3,176, 3,177, 3,178, and 3,179; British Museum Collection E 10,677; F. Braun Collection, two specimens; Indian Creek, Montgomery County, Indiana, F. Springer Collection 8,102.

The specimen figured by Dr. White (1880a), as stated, is in the University of Chicago Collection. As it is not the original single specimen he had when he first published the species,

it is not the type. It is a small individual (Plate 69, figs. 2, 3), about half grown, and is quite typical in form, but somewhat flattened laterally. The ambulacral plates at the mid-zone and throughout the areas are rhombic, as figured by Dr. White, not yet having taken on any of the dorsal and ventral truncation of the plates seen in older specimens. A second specimen in the University of Chicago Collection is from another locality (Plate 69, fig. 4). This is a larger individual, more nearly complete and perfect in form excepting for a little lateral flattening. The ambulacral plates at the mid-zone (Plate 70, fig. 2), instead of being rhombic,

TEXT-FIG. 251.—*Lepidesthes colletti* White. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. Museum of Comparative Zoölogy Collection 3,178 (from R. T. J. Coll.). Same specimen as Plate 69, fig. 1; Plate 78, fig. 1. Ambulacra are dorsally simple. Oculars and genitals are broad, low, rounded; madreporic pores in genital 2.

are narrow hexagons, having a short dorsal and ventral straight edge, but are not nearly so wide as in those of a large individual (Plate 70, fig. 3). In the interambulacra of this specimen (Plate 69, fig. 4) the plates of column 4 are wide in area A, but in area C the wide plates are in column 3.

A fine specimen in the Museum of Comparative Zoölogy shows a dorsal view somewhat compressed, with a side thrust, but all the plates are in place (Plate 69, fig. 1; Plate 71, fig. 1; text-fig. 251). The ambulacral plates are rhombic, with 16 columns in each area at the mid-zone.

Dorsally, near the oculars, there are few, even two plates in one row in an area, and the number of columns increases, passing ventrally, as above described. In the interambulacral areas all four columns continue to the apical disc. In four areas, column 3 consists of wide plates imbricating laterally in two directions, and in these areas there is one column on the left, and two on the right of this wider column. In one area, 4, column 4 consists of wide plates with two columns on the left and one on the right. The apical disc and periproct are well preserved as above described.

A specimen in Mr. Braun's collection (Plate 69, fig. 5) is like that just described, a dorsal view and very well preserved. The ambulacral plates are all rhombic. In the interambulacral areas A and E, column 4 is the wider column, and in C and G, 3 is the wider column; area I is doubtful, but apparently column 3 is composed of wide plates. Periproctal plates, similar to those of text-fig. 251, are in place, but the plates of the apical disc were not worked out.

A choice specimen in the Museum of Comparative Zoölogy is perfect in form from the mid-zone up, but ventrally is somewhat imperfect (Plate 69, fig. 6; Plate 70, fig. 1). The ambulacral plates are for the most part rhombic, but a few at the mid-zone and ventrally have their dorsal and ventral borders more or less completely truncated, forming hexagons. The interambulacral areas are complete, and in both areas A and C, column 3 consists of broad plates imbricating laterally in two directions over the plates of the adjacent columns. Ventrally, the tips of dental pyramids are in place.

A specimen which I gave to the British Museum, and now no. E 10,677 of that collection, is similar to the one just described, but somewhat smaller. It is laterally compressed, and measures 39 mm. in height and 34 mm. in width. The ambulaera measure 13 mm. in width and the interambulaera about 5.5 mm. in width. Ambulacral plates are rhombic, with 16 columns in an area at the mid-zone. The interambulacral areas are not very clearly preserved, but there are four columns in two areas. In area A the plates of column 3 are wider, imbricating laterally in two directions, and in area C the plates of column 4 are wider. The tips of five dental pyramids with traces of teeth are seen ventrally.

A very large and well preserved specimen in the Museum of Comparative Zoölogy shows many interesting characters (Plate 69, fig. 7; Plate 70, figs. 3, 4). This specimen measures 70 mm. in height and about 61 mm. in width. The ambulaera are about 24 mm., and the interambulaera about 10 mm. in width. The ambulacra at the mid-zone are relatively wide hexagons, the dorsal and ventral border of each plate impinging on and truncating ventrally, or truncated dorsally by, the next succeeding plate of its own series. This is quite distinct from the rhombic plates seen at the same area in younger specimens (Plate 71, fig. 1). Dorsally, however, a different condition exists, for in this region, as seen in the middle line of area J (Plate 69, fig. 7), the ambulacral plates are rhombic in shape, therefore in a large individual, as a localized stage, these younger plates have the character of all the plates of a younger individual.

In interambulacrum A there are four columns of plates from the ventral portion as far as preserved to the mid-zone; but above the ambitus, and 14 mm. below the top of the specimen, a fifth column appears in the middle of the area and continues to the dorsal part of the test. This is the only case of more than four columns seen in the species. The interambulacral plates are worn, but bear small secondary tubercles and spines (Plate 70, fig. 4).

Another very large specimen in the Museum of Comparative Zoölogy is remarkably clearly preserved (Plate 69, fig. 8). The ambulacra are relatively very wide, as shown in the figure and by the measurements given above. The ambulacral plates at the mid-zone are relatively wide hexagons, as in the last specimen described, and, again like it, the plates dorsally are rhombic in outline instead of hexagonal. The interambulacra have four columns of plates in areas A and C, and in both the plates of column 3 are wide, imbricating laterally in two directions. Ambulacral and interambulacral plates show well the numerous small secondary tubercles.

****Lepidesthes extremis* sp. nov.**

Text-fig. 252, p. 431; Plate 71, fig. 2; Plate 72, figs. 1, 2; Plate 73, figs. 1, 2.

This interesting species is represented by two specimens which were kindly loaned me for study by Mr. Eber Hyde, of Lancaster, Ohio, through his son, Mr. J. E. Hyde, of Columbia University. The specimens are internal or external molds in a dark siliceous horn-stone, stained a yellowish brown by iron. This species, while known only from portions of the test, and those not at the mid-zone, yet represents the most massive test and proportionately the widest ambulacra known in this striking genus. The fullest idea of the species is gained from the specimen which is an internal mold. This specimen, as far as preserved, measures 93 mm. in width by 45 mm. in a plane at right angles to the same. As it is somewhat compressed and not complete on the periphery, it is difficult to estimate the size, but in the ventral view, Plate 72, fig. 1, from the center to the outer limit of ambulacrum H, it measures about 55 mm. From this radial measurement the test when alive probably measured not less than 100 mm. in diameter. One side of the specimen bears an impression of the ventral portion of the test, and on the reverse side a similar impression of parts of the dorsal portion of the test (Plate 72, figs. 1, 2; Plate 71, fig. 2). No portion of the specimen extends far enough to give the character at the mid-zone, and the ventral impression is the most instructive. In this view and at a zone which is much below the mid-zone (Plate 71, fig. 2) ambulacrum B measures 33 mm. in width in a straight line across from its points of aboral contact with interambulacra A and C. Interambulacrum C measures at its aboral border (Plate 71, fig. 2) 5 mm. in width; therefore the ambulacrum at this zone is something more than six times the width of the interambulacrum, a proportion in excess of that known in any other regular sea-urchin, living or fossil, and in this character approached only by *Meekechinus elegans* (p. 443). The ambulacrum in Echini is

the one most essential feature in their morphology and evolution, and in its great proportionate development to the rest of the test, this species takes rank among the most specialized of known types (p. 234).

The ambulacra, as far aborally as known, have 16 columns of plates in each area, and, as stated, are several times the width of the interambulacra instead of about twice the width, as in *Lepidesthes colletti*. As the impressions of the plates are internal molds, the details are not the same as they would be on the exterior, but the plates are wide and would evidently be hexagonal if the external sutures were visible. The pore-pairs are situated about in the middle line in the lower or adoral half of each plate, a general character of the interior in this genus (compare p. 418, Plate 67, figs. 15, 16). The ambulacral plates evidently imbricate strongly ventrally and laterally bevel under the adradials.

The interambulacral areas, as far as preserved, have four columns of plates in an area (Plate 71, fig. 2), and the same is true of the dorsal side (text-fig. 252), as seen, not very clearly, in Plate 72, fig. 2. As there are four columns, both ventrally and dorsally, this is doubtless the character of the area for the parts which are missing, except the ventral developing area near the peristome. The interambulacral plates are all small, about equal in height to the ambulacrals, both ventrally and dorsally. They imbricate strongly aborally and from the center laterally and over the ambulacra on the adradial sutures. On the exterior, as shown by external molds, the plates are rounded in outline as usual, and bear small secondary tubercles (Plate 73, fig. 1). Crowded masses of spines occur on both specimens as external molds. They are all slender, filiform, swollen at the base, and about 3 to 4 mm. long (Plate 73, fig. 2). Peristomal, apical, and periproctal plates are unknown in this species, but ventrally there are impressions of a powerful lantern.

This species has the same number of columns of ambulacral and interambulacral plates as *Lepidesthes colletti*, but in the extreme width of the ambulacra and narrowness of the interambulacra, it may well be considered the most specialized species of the genus. It is also geologically the highest species of the genus, as it comes from the Coal Measures or Carboniferous proper, whereas all other species are found in the Devonian or Lower Carboniferous.

Putnam Hill Limestone, Carboniferous (Coal Measures), New Lexington, Perry County, Ohio, in the collection of Mr. Eber Hyde, holotype no. 524, paratype no. 525.

TEXT-FIG. 252.—*Lepidesthes extremis* sp. nov.
Internal mold of the dorsal side, same specimen
as Plate 72, fig. 2. Holotype. $\times$ about 1.8.

**Lepidesthes caledonica* sp. nov.

Plate 72, figs. 3-10.

In the British Museum and in the Museum of Practical Geology there are a number of small slabs bearing isolated plates of *Lepidesthes* from Roscobie, Scotland. Excepting the *Lepidesthes devonians* from the Devonian, this is the first case of *Lepidesthes* reported from Great Britain. The number of columns of plates in an area cannot be given, but there is enough detail to warrant considering it distinct from any other known species.

Ambulacral plates are low and wide. The surface of the plates, not counting the beveled edges, measures about 2.5 mm. in width by 1.5 mm. in height. The ambulacral plates are strongly imbricating adorally and laterally beveled under the adradials. The plates figured show the dorsal and lateral beveled edges which respectively would underlie the adoral border of the next ambulacral plate dorsally, or the left adambulacral plates of an interambulacral area (compare text-figs. 32, 33, p. 75). The pore-pairs are in peripodia, lying to the right of the centre of the plates as figured. On the surface of each plate there are about five to eight small secondary tubercles. In one of the specimens four columns of ambulacral plates can be counted in place, indicating that there were at least that number in an area. The interambulacral plates are thin, scale-like, rounded in outline, and imbricate strongly dorsally, as indicated by the wide adoral bevel which would underlie the dorsal border of the next adjacent plate ventrally. The surface of the plates bears numerous small secondary tubercles. Dissociated small secondary spines occur with the plates. These are slender, tapering, expanded at the base, vertically finely striate, and measure from 1.8 to 2 mm. in length. A number of dental pyramids occur with the specimens. These are wide-angled, with a moderately deep foramen magnum. As seen from the interior, the pyramid figured shows part of a grooved tooth in place. Complete teeth seen from the interior and with the tips intact show that the teeth were grooved, as shown by specimens in the British and Jermyn St. Museums. In side view, the pyramids show plicate ridges for the attachment of interpyramidal muscles.

Lower Carboniferous Limestone, Roscobie, Dumfries, Fifeshire, Scotland, British Museum Collection E 10,699 to E 10,723, of which the holotype is E 10,710, the other specimens being paratypes. Additional paratypes from Roscobie, in the Museum of Practical Geology Collection 16,308 and 16,309.

PHOLIDOCIDARIS Meek and Worthen.

Pholidocidaris Meek and Worthen, 1869, p. 78; Lovén, 1874, p. 40; Duncan, 1889a, p. 18; Jackson, 1896, pp. 210, 241; Tornquist, 1897, p. 765; Klem, 1904, p. 22; Lambert and Thiéry, 1910, p. 123.

Protocidaris Whidborne, 1898, p. 202.

Echinocystis (pars) Lambert and Thiéry, 1910, p. 118.

The characters of this genus are taken from the type species, *P. irregularis*, the only one yet known with any degree of completeness. Test spheroidal. Ambulacra are moderately wide; ventrally the plates are large, and dorsally much smaller, with many columns of plates in each area (six columns in *P. irregularis*). Interambulacra are wide, with many columns of plates in each area (five to six in *P. irregularis*). The interambulacral plates are large and scale-like; the adambulacral plates dorsally are much larger than the plates of median columns. They imbricate strongly aborally, from the center outward, and over the ambulacra on the adradial sutures. Adambulacral plates (dorsally) bear a large, eccentric, perforate primary tubercle, and in addition, numerous small secondary tubercles. Plates of median columns (dorsally) bear secondary tubercles only. Ventrally apparently all interambulacral plates are similar, each with a perforate primary tubercle (pp. 435, 437, 439). Primordial interambulacral plates are in the basicoronal row, above which additional columns originate, passing dorsally. The peristome is not known, but probably was covered with ambulacral plates only as in *Lepidesthes* (p. 413). Mr. Agassiz (1881, p. 79) speaks of the peristome of *Pholidocidar* as if it were known, but I believe it has never been described, and if Mr. Agassiz knew what the structure is, he did not describe it. Oculars are doubtful, genitals large, with numerous pores. There is no evidence that the apical disc of *Pholidocidar* is structurally comparable to the apical disc of the *Echinothuriidae* (p. 414), as assumed by Mr. Agassiz (1881, p. 79). The periproct is unknown. The lantern is inclined, and as far as known, with the typical characters of the *Perischoechinoida*.

Type species, *Pholidocidar* *irregularis* (Meek and Worthen) from the Lower Carboniferous of America.

*Key to the Species of Pholidocidar.*¹

Six columns of plates in an ambulacral area and six or five columns of plates in each interambulacral area. Ambulacral plates are large ventrally, small dorsally. Interambulacral plates ventrally of about uniform size; dorsally, adambulacral plates are wider and higher than plates of median columns. Dorsally, primary tubercles are on adambulacral plates only *P. irregularis* (Meek and Worthen), p. 434.

Interambulacral plates, as far as known, are rounded, thin, scale-like, and imbricating, with eccentric primary and secondary tubercles and spines; ambulacral plates are, as far as known, large and rounded, with pore-pairs in the middle of the plates *P. tenuis* Tornquist, p. 440.

Interambulacral plates are polygonal, scale-like, and imbricating, with eccentric primary and secondary tubercles; very imperfectly known; Devonian *P. acuar* (Whidborne), p. 441.

Apparently six columns of hexagonal plates in an ambulacral area, and apparently three or more columns of plates in an interambulacral area, with high, wide, adambulacral plates similar to those of *P. irregularis*; very imperfectly known *P. gaudryi* (Julien), p. 442.

¹ In regard to the names *Pholidocidar* and *P. irregularis*, attention is called to the names *Heterocidar* and *H. leokuk* and *H. laevispina* under *Nomina Nuda* (p. 456).

***Pholidocidaris irregularis** (Meek and Worthen).

Plate 73, figs. 3-7; Plate 74, figs. 1-7; Plate 75, figs. 1-5.

Lepidocentrus irregularis Meek and Worthen, 1869, p. 78.

Pholidocidaris irregularis Meek and Worthen, 1869, p. 78; 1873, p. 512, Plate 15, figs. 4c-4e, 9a-9c; Lovén, 1874, p. 40; Meek, 1874, p. 375; Keyes, 1895, p. 180; Jackson, 1896, p. 210; Tornquist, 1897, p. 766; Klem, 1904, p. 22; Lambert and Thiéry, 1910, p. 123.

Pholidocidaris meeki Jackson, 1896, pp. 210, 241, Plate 9, fig. 54; 1899, p. 132; Tornquist, 1897, p. 766.

This species has been incompletely known, but new material adds considerably to the known facts. This leads me to accept Miss Klem's reference of *P. meeki*, which I described as a new species, to *irregularis* as a synonym. No one specimen is complete, but the characters are gathered from different specimens which are later considered separately.

Test large and spheroidal. In a small specimen, the ventral border of which is about on the plane of the mid-zone (Plate 75, fig. 1), the ambulacra measure 6 mm. in width, the interambulacra 37 mm. in width. Larger specimens greatly exceed this size as gathered from those figured. One imperfect but very large specimen (Plate 74, fig. 2) probably was 100 mm. or more in diameter when alive.

The ambulacra have apparently only six columns in each area (Plate 73, fig. 3; Plate 74, fig. 1). The ambulacral plates in the ventral and dorsal areas differ very much, a peculiarity known in no other Palaeozoic Echini. Ventrally, the ambulacral plates are very large, the largest measuring about 5 to 8 mm. in width, with the pore-pairs about in the middle of each plate, as seen in area D and partially in area B (Plate 74, fig. 1; also Plate 73, figs. 6, 7). On the other hand, the dorsal ambulacral plates in the same specimen are small, about 3 mm. or less in width, as seen in area B (Plate 74, fig. 1; also see Plate 73, figs. 3, 4). This extreme difference in plates ventrally and dorsally I could hardly have believed if I had not actually found them in place in a single specimen, crushed and distorted enough it is true, yet revealing the facts. There are few plates in the ventral portion of the ambulacrum near the peristomal border (Plate 73, fig. 6), although the exact number cannot be stated, and, passing dorsally, the number of plates and apparently the number of columns increases.

The interambulacra are no less remarkable than the ambulacra. At the mid-zone and dorsally (Plate 73, figs. 3, 4) there are five or six columns in each area. The plates are scale-like, rounded on the sutures, and imbricate strongly aborally and from the center laterally and over the ambulacra on the adradial sutures. Dorsally, the plates of the adradial columns are very large, being wide, and in height equaling the height of two or three plates of the median columns (Plate 73, figs. 3, 4). Two large isolated adradial plates (Plate 74, figs. 3, 4) measure respectively 23 mm. in height by 15 mm. in width, and 25 mm. in height by 11 mm. in width. These plates show well the ventral and admedian beveled edges which extended under their

adjacent fellows when in place. They also show the strongly curved outlines which the suture lines of the several adjacent plates possessed. The dorsal adradial plates bear each a large eccentric perforate primary tubercle with scrobicule, and, in addition, small secondary tubercles (Plate 73, figs. 3, 4; Plate 74, figs. 1-5; Plate 75, figs. 1-3). The plates of the median columns dorsally are strongly rounded on the suture lines, and bear secondary tubercles only (Plate 73, figs. 3, 4; Plate 75, figs. 1-3). The ventral part of the test is known from Meek and Worthen's figure (my Plate 75, fig. 4), also from the interior as seen in part in Plate 74, figs. 1 and 2, and from the exterior as seen in Plate 73, fig. 6.¹ This last specimen is somewhat confused and difficult to study, yet it shows important features. The primordial interambulacral plate is in place in the basicoronal row as seen in area C. There are two plates in the second row and three in the third row; thus the third column originates in the third row as usual in the Palaeozoic species in which the base of the corona has not been resorbed in the advance of the peristome (p. 66; text-fig. 30, p. 70). There are three rows of three plates before the fourth column originates in the sixth row. This is very late for the fourth column to develop, the latest of any case figured in this memoir, and it is very likely exceptional for the species, but on this point there are no other specimens as yet known for comparison (p. 439). The fifth column originates in the seventh row (the next row after the introduction of the fourth) and the sixth column originates in the eighth row. These plates all imbricate aborally and from the center laterally and over the ambulacra on the adradial sutures. All interambulacral plates on the ventral side are of about the same size as far as this figure shows (Plate 73, fig. 6), the adradial plates not being strikingly different from plates of the median columns as they are on the dorsal side (Plate 73, figs. 4, 5). The plates of this specimen are much worn, but the adradial plates, and also the median plates bear a large perforate eccentric primary tubercle, doubtless with, in addition, secondary tubercles, but these latter, if they existed, are worn off. There are therefore primary tubercles on all interambulacral plates ventrally, whereas they exist only on adradial interambulacral plates dorsally. The primary spines are rather stout, enlarged at the base, terete. Meek and Worthen say that the larger primary spines attain a length of about an inch and a thickness of 0.1 inch at the base, which is swollen (Plate 75, figs. 4, 5). The largest that I have seen measure about 12 mm. in length (Plate 73, fig. 5). Secondary spines are small, filiform, expanded at the base, and measure about 3 to 4 mm. in length (Plate 75, fig. 4; Plate 73, fig. 5).

The apical disc is only partially known, but it is evidently small in proportion to the diameter of the test. A small plate dorsal to ambulaerum B, in Plate 73, fig. 3, has two pores, and may be an ocular (p. 419), but other oculars, if present in any of the specimens, are not recognized. The genitals are high and wide, with many genital pores, up to ten counted in one

¹ This figure is of the specimen which I earlier described as *P. meeki*, but which is now referred to *irregularis* as a synonym, as discussed on p. 438.

plate (Plate 73, figs. 3, 4; Plate 74, fig. 1). The lantern is inclined, teeth are grooved, and pyramids wide-angled, with moderately deep foramen magnum (Plate 74, figs. 2, 6, 7).

Keokuk Group, Lower Carboniferous, Hamilton, and near Nauvoo, Illinois; these are the original localities given by Meek and Worthen. The type is said to be in the Worthen Collection which is now in the University of Illinois, at Urbana, Illinois. Keokuk Group, Keokuk, Iowa, F. Springer Collection 8,015, 8,017; Montgomery County, Indiana, F. Braun Collection, two specimens; Warsaw, Illinois, Museum of Comparative Zoölogy Collection 3,070; Keokuk, Iowa, two interambulacral plates, Museum of Comparative Zoölogy Collection 3,182; near Burlington, Iowa, University of Michigan Collection 1,740. Lower Carboniferous, Omer, Michigan, dissociated plates that I collected at that locality, Museum of Comparative Zoölogy Collection.

Up to the present, the best published figure of this species is that given by Meek and Worthen (1873), here reproduced as Plate 75, fig. 3. As they had no genital plates, or other structures to locate the axes, their figure was incorrectly oriented, which led to a wrong impression as regards the direction of imbrication (p. 76). The orientation is corrected in my Plate, and therefore shows the imbrication of interambulacral plates as aboral, which is correct. In this figure in area A there are a left adradial and three median columns. The adradial plates are very large and have the eccentric perforate primary tubercles, with numerous small secondaries characteristic of this column dorsally. The median plates have secondary tubercles only. All the plates are strongly curved outward and rounded on the suture lines as is typical of the species. In ambulaerum B there are four small ambulacral plates, not in place, but typical of the dorsal side. In addition, there is a quantity of small bodies, plates perhaps, which are apparently foreign to the specimen, and are scattered indiscriminately in ambulacral and interambulacral areas. Meek and Worthen's figure of the reverse side of the same specimen, reproduced as my Plate 75, fig. 4, shows a confused mass of plates from the ventral side. The ambulacral plates are rounded in outline, and much larger than on the dorsal side. The pore-pairs are about in the middle of each plate, and are surrounded by a sunken ring, and the pores are on an elevated prominence, resembling the holes on the back of a button. The interambulacral plates are small, mostly with primary and secondary tubercles, and numerous primary and secondary spines are scattered over the plates. A single primary spine restored, and magnified "about twice," copied from Meek and Worthen (my Plate 75, fig. 5), shows the form well; it is considerably larger than any spine of this species that I have seen.

Mr. Braun's specimen, from Montgomery County, Indiana (Plate 75, fig. 2; Plate 73, figs. 4, 5), is a small individual, but it is the most nearly complete dorsal view of any specimen known. On account of the lightness and delicacy of the test of this specimen and the next one described (Plate 75, fig. 1; Plate 73, fig. 3), my first impression was that it represented a distinct species, but as the structural characters are the same as in large undoubted specimens

of *irregularis*, it seems safest to ascribe the differences to immaturity. In this very choice specimen (Plate 73, fig. 4) ambulacral plates are in place in all five areas. Dorsally in area B, also in area D, there are only four columns. The ambulacral plates are all very small, like the dorsal plates in Plate 74, figs. 1, 2. The interambulacral areas are in part well preserved, and are by all means the most nearly complete of any known specimen. The adradial plates in each area are wide, very high, and about the height of two to three plates of the median columns. The adradials bear an eccentric primary with secondary tubercles, the median plates secondary tubercles only, though for the most part these have been omitted in the drawing. They can be seen, however, in the photographic figure (Plate 75, fig. 2), and are shown in the drawing of another specimen (Plate 73, fig. 3). In interambulacrum A there are six columns of plates, the sixth coming in above the adoral border and represented by only three plates, above which to the apical disc there are only five columns (Plate 73, fig. 4). In area I a sixth column is also represented by some plates. In area C there are only five columns, all of which extend throughout the area as far as preserved. Area E is doubtful, but there are apparently five columns in area G; of course, ventrally in this area, if preserved, there might have been a sixth column represented as in area A. A genital plate is in place, capping area A. It is a low, broad, rounded plate, with seven pores. Another genital, capping I, but somewhat displaced, shows only five pores. No ocular or periproctal plates were recognized.

Another immature specimen, quite similar to that just described, is from Keokuk, Iowa, in Mr. Frank Springer's collection. This specimen (Plate 75, fig. 1; Plate 73, fig. 3) has parts of three ambulacral and two very good interambulacral areas. The adoral border is about on the line of the mid-zone. The ambulacral plates are all small, and in area D there are three columns of plates which evidently belong to the right half-area, and thus represent six columns for the whole area at this zone. In both interambulacral areas the adambulacral plates are wide and very high, equaling the height of two to three median plates in the same zone. It is to be noted that this great size and especially the great elongation of adradial plates are most marked in the three or four more dorsal plates of each column, and near the mid-zone the adradial plates are much lower, as seen in Plate 73, figs. 3, 4, and Plate 75, fig. 3. On the ventral side of another specimen (Plate 73, fig. 6) it is seen that in area C the plates of the adradial columns are no wider nor higher than are the plates of median columns. It is evident therefore that this specialization of adradial plates is a character taken on late in development and occurs only in the dorsal portion of the test. The adradial plates have a large eccentric perforate primary tubercle and numerous small secondary tubercles (Plate 73, fig. 3), except that the one youngest plate next the apical disc in each adradial column has not yet acquired the primary tubercle. This is a general character of youthful plates in the placogenous zone (compare text-figs. 92, 94, and 96, pp. 106, 107, 108; Plate 11, fig. 2). The plates of the median columns have secondary tubercles only (Plate 73, fig. 3). There are six columns of interambulacral

plates in the two areas preserved, but in area A column 5 and in area C column 6 drop out early, above which five columns extend to the apical disc. A small plate with two pores above ambulacrum B may be an ocular; if so, it is the only ocular yet recognized in the genus (p. 433). A genital above interambulacrum A is a large, rounded plate with ten genital pores.

A small series of isolated interambulacral plates from near Burlington, Iowa, in the University of Michigan Collection, is instructive as they are sharply and clearly preserved (Plate 74, figs. 3-5). The plates are all from adradial columns as indicated by the presence of a primary tubercle on each, and the beveled edges extending adorally and admedially demonstrate that figures 3 and 5 are from a left adradial and figure 4 from a right adradial column. The plates shown in Plate 74, figs. 3, 4, are high and wide, and would belong to the dorsal portion of a test. The plate shown in Plate 74, fig. 5, is low and wide; it could not be a young plate dorsally, as the primary tubercle is well developed, and it may have come from about the mid-zone or farther adorally. A right half-pyramid (Plate 74, fig. 6) indicates that the pyramid was wide-angled with moderately deep foramen magnum; the suture for the epiphyses is seen dorsally. Another half-pyramid seen from within (Plate 74, fig. 7) shows that the lateral wing is wide, indicating an inclined lantern (compare Plate 12, figs. 6-8). This specimen shows the pyramidal suture and dental slide for the support of the tooth, the slide failing to reach the base of the foramen magnum as usual in the *Perischoechinoida* (compare Plate 2, fig. 10).

An important, but somewhat imperfectly preserved specimen, showing the ventral part of the test, is in the Museum of Comparative Zoölogy. This specimen is from Warsaw, Illinois (Plate 73, figs. 6, 7), and I described it (1896, p. 210) as the type of a new species, *Pholidocidaris meeki*. I did not then recognize the differences that exist between the ventral and dorsal parts of the test, so that it was felt the differences warranted specific distinction. Miss Klem (1904, p. 23) treated *meeki* as a synonym of *irregularis*, and I quite agree with her. In my earlier publication errors were made which require correction. On page 211 (of Jackson, 1896) it is stated that the plates of both ambulacral and interambulacral areas imbricate adorally. This is true of the ambulacral plates, but interambulacral plates imbricate aborally, and from the center outward and over ambulacrals on the adradial suture as usual (discussion, p. 76). Another error was made in the drawing of Plate 9, fig. 54, in which I showed column 4 as originating in the fourth row, whereas it does not originate until two rows later, as seen in the present figure. In this specimen (Plate 73, figs. 6, 7) the ambulacral plates are very large, somewhat irregular in shape, but approaching rhombic in form. Dorsally, on the aboral border, some small ambulacral plates appear, having taken on the character typical of all the plates dorsally. The pore-pairs are about in the middle of each plate in a raised area, and resemble the holes in a button. The ambulacral plates imbricate adorally and laterally bevel under the adradials. The specimen is too much worn to show secondary tubercles, which alone probably existed on the ambulacral plates. As briefly considered above, the primordial inter-

ambulaeral plate is in the basicoronal row in area C, and this specimen was one of the first of Palaeozoic Echini in which this structure was discovered. I correlated it with the single plate at the ventral border in *Bothriocidaris* and the young of Recent Echini (Jackson, 1896, pp. 212, 230). In the second row there are two plates as a second stage in development, and in the third row three plates. This is all as usual in the development of all Palaeozoic Echini in which the primordial interambulaeral plate is retained (Plate 25, fig. 1), excepting *Bothriocidaris*, in which there is only a single column of plates in an area (Plate 1, fig. 1). In this area of this specimen of *Pholidocidaris* there are also three plates in the fourth and fifth rows (Plate 73, fig. 6). In the sixth row there are four plates, column 4 originating on the right of the center as usual. This is, however, a very unusual case in that column 4 originates so late. It ordinarily originates in the next row after the introduction of column 3, so that there is typically in Palaeozoic Echini only one row ventrally with three plates (text-figs. 25, 30, p. 70). In *Palaeochinus quadriserialis* in area C (Plate 30, fig. 3), and in *Lovenechinus septies*, also in area C (Plate 45, fig. 1), there are two rows of three plates before the introduction of column 4. Again, in a specimen of *Melonechinus multiporus*, figured by Jackson and Jaggar (1896, Plate 3, fig. 12; Plate 4, fig. 18) there are at least four rows of three plates before the introduction of the fourth column (p. 377). These are all rare and exceptional variations of retarded development, and with *Pholidocidaris irregularis* are the only cases seen in which the fourth column (when existent) did not originate in the next row after the third (p. 349). In *Pholidocidaris irregularis* (Plate 73, fig. 6) the fifth column originates in the seventh row, immediately after the fourth, and the sixth column originates in the eighth row, immediately after the fifth, thus, as regards these two, showing an accelerated development. The plates of interambulaerum A are so confused that they do not show much structure. Fragments of primary spines occur scattered over the test.

A fragment of a large crushed test from Montgomery County, Indiana, in Mr. Braun's collection, is very instructive. This specimen (Plate 74, fig. 1) is a portion of a test extending from the apical disc nearly or quite to the mid-zone. The dorsal plates are seen from the exterior and are not shaded. Part of the dorsal plates are wanting, so that ventral plates are seen from the interior, and are shaded to differentiate them. From this peculiar condition of preservation the ventral plates can be directly compared with the dorsal plates of the same specimen. The ventral ambulaeral plates are very large, from 5 to 7 mm. in width, with pore-pairs about in the middle of each plate, as seen well in area D. In contradistinction, the dorsal ambulaeral plates are small, about 2 to 3 mm. in width. This extraordinary difference in the ventral and dorsal ambulaeral plates (p. 434), is shown more strikingly in this than in any other known specimen. The adradial dorsal interambulaeral plates are wide and high as usual. Dorsally, there are two genital plates which are wide and rounded in outline, each with many pores. A fragment of a lantern shows in part a brace, two epiphyses, and part of a pyramid.

Another similar crushed specimen from Keokuk, Iowa, is in Mr. Frank Springer's collection. It is a very large individual (Plate 74, fig. 2); the dorsal plates are seen in external view, and, where wanting, part of the ventral plates are seen from the interior and are shaded for contrast. The ambulaeral plates are mostly dorsal and therefore small. The adradial plates are large and rounded, as usual, and plates of the median interambulaeral columns are smaller. Although fragmentary, it seems that six columns can be made out in each interambulaeral area. A lantern in place is strongly inclined with grooved teeth, and the dorsal borders of ten half-pyramids are in place.

* *Pholidocidaris* sp.

Plate 74, figs. 8-10.

In a small slab from the Kaskaskia Group, Lower Carboniferous, of Pulaski County, Kentucky, in Mr. Frank Springer's collection, there are a number of small plates referable to *Pholidocidaris*. They may be young specimens of *irregularis*, or they may be a distinct species, but there is not enough structure to base any conclusions on. The interest of it is that specimens of the genus occur in this locality and horizon.

The ambulacral plates are typical of those from the ventral area in *Pholidocidaris* and unlike anything known in other genera. Two genital plates are high and wide, with numerous pores.

* *Pholidocidaris tenuis* Tornquist.

Plate 72, fig. 11; Plate 74, figs. 12, 13.

Pholidocidaris tenuis Tornquist, 1897, p. 767, Plate 21, figs. 8, 9; Plate 22, fig. 8; Klem, 1904, p. 23; Lambert and Thiéry, 1910, p. 123.

This species was described by Professor Tornquist from numerous interambulacral plates and also primary spines from the Lower Carboniferous of Alsace, Germany. A specimen from the Lower Carboniferous of Lancashire, England, in the Museum of Practical Geology, appears to be referable to this species, and adds something to the known characters and also to the geographical distribution of the species.

According to Tornquist's description, the interambulacral plates are all of about equal size, 10 mm. in width, irregularly hexagonal, thin, and strongly imbricating. Each plate bears an eccentric large perforate primary tubercle with numerous secondary tubercles (Plate 74, fig. 12). The primary spines are terete, expanded at the base, nearly smooth, but with fine vertical striae which are seen only on considerable magnification. They measure from 10 to 15 mm. in length (Plate 74, fig. 13).

The English specimen consists of a slab 150 mm. long by 70 mm. wide, which bears a confused mass of dissociated plates, part of which are shown in Plate 72, fig. 11. The interambulacral plates are thin, scale-like, strongly imbricating. They measure from 8 to 11.5 mm. in

width, and are of about equal height. The interambulaeral plates bear a large eccentric perforate primary tubercle and secondary tubercles. They are quite similar in size and ornamentation to those described by Tornquist. In addition, some relatively large ambulaeral plates occur. These are slightly wider than high; they measure about 8.3 to 11 mm. in width and have a pore-pair nearly or quite in the center of the plates. With these large ambulaeral plates are some that are very much smaller, which are probably dorsal plates. In the larger plates the pore-pairs are surrounded by a depressed ring, as is typical of the ventral ambulaeral plates in *Pholidocidaris irregularis*. On the reverse side of the slab are found a number of primary and secondary spines. The primary spines are swollen at the base, terete, about 7.2 to 8.4 mm. in length, and marked by very fine longitudinal striae. The secondary spines are much smaller, about 2.8 mm. in length, and show no vertical striae. The number of columns of ambulaeral and interambulaeral plates in an area is unknown, but from the large number of interambulaeral plates in the English specimen, which apparently represents a single individual, there are probably a good many columns in an area. A large stout tooth, which, as far as preserved, measures 28 mm. in length and is 9 mm. wide, bears evidence of a powerful lantern.

Lower Carboniferous, Hunsrück, Alsace, Germany; Coplaw, Clitheroe, Lancashire, Museum of Practical Geology Collection 16,304. This is the first occurrence of *Pholidocidaris* recorded from the Lower Carboniferous of Great Britain, but it occurs in the Devonian, as seen from the next species described.

* *Pholidocidaris acuaria* (Whidborne).

Plate 74, fig. 11.

Eocidaris (?) *acuaria* Whidborne, 1896, p. 376.

Protocidaris acuaria Whidborne, 1898, p. 203, Plate 25, figs. 1-1b, 2, 2a; Klem, 1904, p. 75.

Protocidaris [acuaria] Sollas, 1899, p. 709.

Echinocystis acuaria Lambert and Thiéry, 1910, p. 118.

This species is known only from external molds, which are confused masses of plates and spines. Judging from the molds, the interambulaeral plates are large, from 4 to 5 mm. in width, with an eccentric perforate primary tubercle and scrobicule and secondary tubercles. Whidborne says that the primary tubercle is central, but it is certainly not central in some plates, and I have seen no proof that it is central in any plates.

There are impressions of a few large and also small ambulaeral plates with a pair of pores in each; in fact it is by the two small plugs representing casts of the pores that these plates are recognized. The spines are primaries and secondaries; the primaries are swollen at the base, otherwise about cylindrical, and the longest that I saw measured about 6 mm. in length, but they were not complete distally. The impressions of a stout lantern are plainly seen in one of the specimens in the Jermyn St. Museum, no. 7,158.

This species is incompletely known, but I think it is clearly referable to the genus *Pholidocidar*. Whidborne made the species the type of a new genus, *Protocidar*. I see no need of maintaining this genus, for the species as far as known fits well in the genus *Pholidocidar*. It certainly does not belong to the genus *Echinocystis* [*Echinocystites*] to which it is referred by Messrs. Lambert and Thiéry.

Upper Devonian, East of Barnstaple, England, cotypes, Museum of Practical Geology Collection 7,158, 7,159, and 16,358. The specimen no. 7,158 is the original of Whidborne's Plate 25, fig. 1. Same locality, Oxford Museum (Sollas).

***Pholidocidar* *gaudryi* (Julien).**

Lepidocentrus münsterianus Julien, 1874, p. 76 (non de Koninck, 1869, p. 546, for which see *Archaeocidar* *muensteriana*, p. 280).

Melonites gaudryi Julien, 1890, p. 737.

Pholidocidar *gaudryi* Julien, 1896, p. 131, Plate 16, figs. 1, 2, 6, 7; Lambert and Thiéry, 1910, p. 123.

This species is known only from fragmentary molds of plates and spines, and the description is gathered from Professor Julien's text and rather indistinct photographic figures.

Ambulacra are arranged in six columns, limited on either side by adambulacral plates. The ambulacral plates are hexagonal, 4 mm. wide, and about 1.5 mm. high, with pore-pairs near the ventral border of each plate. They are ornamented on the exterior with a large, and also small tubercles. The number of interambulacral columns is unknown, but a badly preserved specimen led Julien to think that there are at least three columns in the neighborhood of the apex. The interambulacral plates are irregular in form, and Julien says that they are similar in form to those of *P. irregularis*. Two of the plates which he figures (his Plate 16, figs. 6, 7c) are wide, high, rounded plates, with eccentric primary and secondary tubercles. These from their shape and size are apparently plates from a right adambulacral column similar to what I show in Plate 74, fig. 4. Julien says that the spines are of various sizes, expanded at the base, terete, marked with fine longitudinal striae, and identical with those of *Pholidocidar* *irregularis*.

Lower Carboniferous, l'Ardoisière, central France. The types are in the possession of the family of the late Professor Julien.

MEEKECHINUS gen. nov.

Test spheroidal, or flattened. The ambulacra are wide at the mid-zone, with in each area numerous columns of small plates (twenty in the known species), and the interambulacra are narrow, with in each area few columns of plates (three in the known species), all plates are of about equal size. A small perforate primary tubercle with scrobicule and secondary tubercles occur on ambulacral and interambulacral plates, also small primary and secondary spines on

ambulacral and interambulacral plates. The peristome and ventral part of the test is fragmentarily known. Oculars are small, imperforate, covering the ambulacra and laterally in part the interambulacra on either side. Genitals are large, with from two to five genital pores. A well developed madreporite exists in the known specimens. The lantern is inclined, of the usual Palaeozoic character, but the teeth on the outer face are vertically ridged and distally deeply serrate, a unique character.

This genus structurally differs from *Pholidocidaris* in that the dorsal interambulacral plates are uniform in size and character instead of very dissimilar; it differs from all known genera in the serrate teeth. I name this genus for the late Fielding Bradford Meek in recognition of his critical and very accurate work on Palaeozoic Echini.

The type and only known species is *Meekechinus elegans* sp. nov. from the Permian of Kansas.

****Meekechinus elegans* sp. nov.**

Plate 75, figs. 6-8; Plate 76, figs. 1-9.

This species is known from three excellent specimens that were kindly sent me for study by Professor J. W. Beede of Indiana University. The specimens consist of two very wonderfully preserved tests, seen in dorsal view, which are very nearly perfect from the apical disc to the ambitus, and a third fragmentary specimen with ventral plates and a fine lantern.

The test is spheroidal or flattened, probably the latter, as the tests are now quite flat and without any obvious displacement of plates, and quite circular in outline, as seen from above. Both specimens are very nearly alike in size and preservation, but that selected as the holotype (Plate 75, fig. 6; Plate 76, fig. 1) measures 54 mm. in diameter through the axis III, 5. From the center of the apical disc to the periphery of the test it measures almost exactly 27 mm. radially in every direction, attesting to the absence of any distortion. At the periphery, which I take to be the ambitus, the ambulacra measure 26 mm. in width in a straight line, or about 32 mm. in width following the curve of the periphery. The interambulacra measure 6 mm. in width, and are strikingly uniform in their constant width from the ambitus to the apical disc. In this respect they surpass any sea-urchin known to me. As seen from the measurements, the ambulacra, measured on the curve of the periphery, are about five times the width of the interambulacra, certainly an extraordinary development for the group, and in all Echini surpassed in this character only by *Lepidesthes extremis*, which proportionately has slightly wider ambulacra, as described on page 430.

The ambulacra are very wide, and at the ambitus, which is also doubtless the mid-zone, there are twenty columns of plates in an area. Sixteen columns is the highest number known in any other sea-urchin (*Lepidesthes colletti* and *extremis*), so that in the number of columns at the ambitus this species surpasses all known Echini. Dorsally, next to the oculars there are

one or two plates in an ambulacral area, from which simple condition as a localized stage, the number of columns of plates increases passing ventrally until the full number is attained at or near the ambitus. The ambulacral plates are low, wide rhombs (Plate 76, figs. 2, 3), and imbricate strongly adorally and laterally bevel under the adradials. The pore-pairs are situated in peripodia, and in each plate lie a little nearer the next adjacent interambulacrum than the middle of the plate. Each ambulacral plate bears a small perforate primary tubercle with a scrobicule and also a number of small secondary tubercles. The larger tubercles bear small primary spines which are terete, swollen at the base, and longitudinally finely striate, measuring about 3 mm. in length. On account of their small size it might be doubted whether these should be called primary spines, but I do so because they are associated with the larger, minutely perforate tubercles which bear a scrobicule. The secondary spines are similar but smaller, and measure up to about 1 mm. in length.

Besides spines, a number of pedicellariae were found in these choice specimens (Plate 76, figs. 8, 9). The pedicellariae are tridentate, similar to the character found in Recent Echini, and measure about 0.5 mm. in length. They are the first pedicellariae found in the Palaeozoic. It is interesting to find that these minute structures of the common typical form, as seen in modern Echini, already existed in these ancient times. Groom (1887) described pedicellariae in the Jurassic *Pelanechinus corallinus* and these with the pedicellariae of *Meekechinus* are the only ones known to me so far found as fossils (p. 61).

The interambulacra are relatively and actually very narrow as above stated, and as far as preserved, consist of three columns of plates throughout each area. Except *Bothriocidaris* which has one column, and *Miocidaris* which has two columns in each area, all Palaeozoic Echini have three or more columns of plates in each interambulacral area. Only rarely are three columns characteristic of the adult, but a three-column stage is typically represented by one row of plates ventrally in species that attain a higher number of columns (text-figs. 25, 30, p. 70). Three Palaeozoic species have three columns as an adult character: the present species, *Melonechinus obovatus* sp. nov. (p. 374; Plate 53, figs. 9, 10), and *Lepidesthes wortheni* Jackson (p. 416; Plate 66, figs. 1-3; Plate 67, figs. 8, 9). This last species, however, has four columns ventrally as a stage in early development. The interambulacral plates of *Meekechinus elegans* are small, rounded on the suture line, about as high as two ambulacral plates, and imbricate strongly aborally and from the center laterally and over the ambulacra on the adradial suture (Plate 76, figs. 4, 5). Each plate typically bears a small, central, perforate primary tubercle with a scrobicule and many small secondary tubercles. On the other hand, in *Pholidocidaris* the primary tubercles are eccentric, and at least dorsally are wanting on the plates of median columns. The spines of interambulacral plates are small primaries and secondaries, similar to those described in the ambulacra. The plates of the ventral area are known only from a fragment of the test associated with the lantern (Plate 75, fig. 8). Here,

as far as observed, ambulacral and interambulacral plates are essentially the same as they are on the dorsal side. A few ambulacral plates are clinging to the oral face of the lantern and are probably peristomal, but they are not sufficiently continuous or complete to be certain. Ambulacral plates only on the peristome is the character to be expected, as that is the structure of the allied *Lepidesthes* (Plate 68, fig. 3).

Dorsally, the apical disc is in place and, though not perfect, is well preserved. In the holotype (Plate 75, fig. 6) the apical disc measures about 9 mm. in diameter through the axis III, 5, which is proportionately about 16 % of the diameter of the test (pp. 87, 362). The oculars are small and imperforate, ventrally covering the ambulacra and laterally in part the interambulacra on either side. The youngest interambulacral plates of each area are in contact with the oculars of either side, as seen best in interambulacrum 2, Plate 76, fig. 6. Oculars II and III are exsert, being shut out from the periproct by the contact of the associated genitals. Ocular V is probably insert, I is wanting, and ocular IV is doubtful. The genitals are all present. Genitals 1, 3, 4, and 5 are all medium sized, rounded in outline, and of about equal size. Each of them bears a small perforate primary tubercle with a scrobicule and smaller secondary tubercles similar to those on interambulacral plates. Genital 1 has five pores, 3 and 4 have four pores each, and genital 5 has three pores. Genital 2, the madreporite, is very much larger than the other genitals. It has numerous fine madreporic pores as in a Recent *Cidaris*, and is the clearest madreporite seen in the Palaeozoic (p. 172). There are in this plate only two genital pores. It bears no primary but a few secondary tubercles scattered amongst the madreporic pores just as can be seen in a modern cidarid, as *Eucidaris tribuloides* (text-figs. 62-69, p. 98). A few small periproctal plates are present, rounded in outline, but somewhat angular, and in general similar to the periproctal plates of other Palaeozoic Echini and modern cidarids (p. 174).

An excellent lantern is preserved in one of the specimens (Plate 75, fig. 8; Plate 76, fig. 7). It is inclined, with pyramids wide-angled as in other Palaeozoic Echini. The most important feature of the lantern in this species is the teeth, which are grooved on the inner face, vertically ribbed on the outer face, and, as a very important character, are distally sharply and deeply serrate as seen clearly in two teeth figured (Plate 75, fig. 8; Plate 76, fig. 7). This distal serration is a unique character in Echini as far as I am aware. Taking up the other characters of the lantern, in area E the two half-pyramids are in contact on the line of the interpyramidal suture. In this area it is seen that the foramen magnum is very deep, more so than in any other Palaeozoic species seen (compare Plate 27, figs. 4-6; text-figs. 207-213, p. 184). On the left half-pyramid the suture exists for the epiphysis, but that structure is wanting in this area. The epiphysis is in place, however, capping the right half-pyramid of area C, and above it lies the tip of a somewhat displaced brace. Due to a local twist, the outer side of the left half-pyramid of area A is seen, and this face has plicate ridges for the attachment of interpyram-

idal muscles as usual in regular Echini. Below the pyramid E a distally forked plate occurs, which is apparently a compass out of place (p. 182).

The specimens of this species were collected recently by Professor J. W. Beede in the Eskridge shales which are in the base of the Permian, at Grand Summit, Kansas. The three specimens described, including the holotype and two paratypes, are in the collections of the University of Kansas.

The first species described in the systematic portion of this memoir is *Bothriocidaris archaica* sp. nov. from the Ordovician, the oldest formation from which Echini are known, and that species, as I have attempted to show, is most primitive in structure, having features in the adult which are like the young of all succeeding Echini. On the other hand, *Meekechinus elegans*, which in the regular series is the last species considered, comes from the highest geological formation, the Permian, in which the order Perischocchinoida is known. Structurally, as regards the development of the ambulacrum and the possession of serrate teeth, it is the most highly evolved of Palaeozoic species, and one of the most specialized of known Echini. As regards the narrow interambulacra composed of only three columns of plates, it is also highly specialized. It makes a fitting climax to the series of remarkable forms which are preserved to us from these ancient geological formations.

INCERTAE SEDIS.

In this section are considered all described Palaeozoic species of Echini that I cannot reasonably place in a definite genus, or intercalate in the systematic descriptions.

***Archaeocidaris konincki* Desor.**

Plate 15, figs. 13a-13d.

Archaeocidaris konincki Desor, 1858, p. 155, Plate 21, figs. 7-10; Klem, 1904, p. 63.

Eocidaris konincki Lambert and Thiéry, 1910, p. 126.

Known only from isolated interambulacral plates as figured.

Lower Carboniferous, Tournay, Belgium.

***Archaeocidaris ladina* Stache.**

Plate 15, figs. 15a-15d.

Archaeocidaris ladina Stache, 1877, explanation of Plate 5, figs. 11, 12; Lambert and Thiéry, 1910, p. 125.

Known only from small fragments of spines with rather large spinules.

Bellerophonkalke, Lower Carboniferous, St. Martin, South Tyrol.

***Archaeocidaris scotica* Young.**

Archaeocidaris scotica Young, 1876, p. 230; Smith, 1901, p. 509; Lambert and Thiéry, 1910, p. 125.

This species is named from jaws, which are probably not generically or specifically recognizable. They have not been figured.

Lower Carboniferous, Craigenglen, Campsie, Scotland.

***Archaeocidaris selwyni* R. Etheridge, Jr**

Plate 15, figs. 9, 10.

Archaeocidaris (?) *selwyni* R. Etheridge, Jr., 1892a, p. 67, Plate 15, figs. 1-3; Klem, 1904, p. 64.

Archaeocidaris sp. R. Etheridge, Jr., 1892a, p. 69, Plate 22, fig. 1; Klem, 1904, p. 65.

Archaeocidaris selwyni Lambert and Thiéry, 1910, p. 125.

Known from nearly complete tests, but the spines are unknown. What position it would take in relation to other species of the genus if we had the spines, is of course undeterminable. Test large, fully four and a half inches in diameter at the greatest periphery. Ambulacra narrow, plates low. Four columns of plates in an interambulacral area. The interambulacral plates are very large and hexagonal, or in adradial columns pentagonal, and rounded on the adradial suture, with very large primary tubercles. Etheridge says that the plates are in four and perhaps five series. I see no indication of a fifth column in his figures, and as the other species of the genus always have four columns in an area when this is completely known, it is probable that *selwyni* has also (p. 257). Powerful jaws are present. Etheridge expresses the view that the two specimens he figures belong to distinct species on account of the shape of the plates, they being proportionately lower in the second and smaller specimen (my Plate 15, fig. 10), to which he does not give any name. Unless further evidence develops, I think they can be safely considered one species, the differences being ascribed to age, as the two differ considerably in size.

Upper Marine Series, Permo-Carboniferous, the holotype from Nowra, Shoalhaven River, County St. Vincent; the second specimen from the same horizon, about five miles south of West Maitland, County Northumberland, New South Wales.

***Archaeocidaris sixi* Barrois.**

Plate 10, figs. 11a-11c.

Archaeocidaris sixi Barrois, 1882, p. 320, Plate 16, figs. 5a-5c; Lambert and Thiéry, 1910, p. 125.

Known fragmentarily only from isolated plates and spines. Interambulacral plates hexagonal; the height equals the width as figured. The spine is compressed, 6 mm. in length, ornamented with fine vertical striae, and with a weakly defined annulus. On account of the small size of the spine in relation to the interambulacral plates, also on account of the

shape of the spine and its weak annulus, this is apparently a secondary, not a primary spine. Secondary spines, as far as known, are alike throughout the genus, and lack the diagnostic character of primary spines; therefore this species cannot be located in its relation to other species of the genus, and is considered here.

Lower Carboniferous, Assise de Lena: Ontoria, Sebarga, Spain.

***Archaeocidaris trautscholdi* Tornquist.**

Plate 15, fig. 14.

Archaeocidaris trautscholdi Tornquist, 1896, p. 29, Plate 4, fig. 1; Klem, 1904, p. 65.

Cidarotropus trautscholdi Lambert and Thiéry, 1910, p. 125.

Not recognizable.

Lower Carboniferous, Miatschkowa, near Moscow, Russia.

***Archaeocidaris* sp. Meek and Hayden.**

Archaeocidaris sp. Meek and Hayden, 1859, p. 25; Klem, 1904, p. 66.

Coal Measures, Cottonwood Creek, Kansas.

***Archaeocidaris* sp. Meek and Hayden.**

Archaeocidaris sp. Meek and Hayden, 1859, p. 25; Klem, 1904, p. 66.

Coal Measures, Cottonwood Creek and Manhattan, Kansas.

***Archaeocidaris* sp. Stache.**

Archaeocidaris sp. Stache, 1877, p. 318, Plate 1, figs. 13-17; Klem, 1904, p. 66.

Bellerophonkalke, Lower Carboniferous, South Tyrol.

***Archaeocidaris* (?) sp. Worthen and Miller.**

Archaeocidaris (?) sp. Worthen and Miller, 1883, Plate 30, figs. 16a-16c.

Good figures of pyramids of a lantern from the Upper Coal Measures of La Salle, Illinois

***Archaeocidaris* sp. R. Etheridge, Jr.**

Archaeocidaris sp. R. Etheridge, Jr., 1892, p. 213; 1892a, p. 67; Klem, 1904, p. 65.

A single interambulacral plate is described as hexagonal with granular margins and central, strong, well marked tubercle. Etheridge remarks that he believes that this is the first announcement of the occurrence of the Palaeochinoida in the Australian Permo-Carboniferous rocks.

Gympie Beds, Permo-Carboniferous, Rockhampton District, Australia.

Archaeocidaris sp. Julien.

Archaeocidaris sp. Julien, 1896, p. 126, Plate 16, figs. 14, 17; Plate 17, figs. 8, 10; Klem, 1904, p. 66.

Spines with four ranges of spinules, perhaps referable to *A. rankini* Young (p. 276).

Lower Carboniferous, l'Ardoisière, France.

Archaeocidaris sp. Julien.

Archaeocidaris sp. Julien, 1896, p. 126, Plate 16, figs. 13, 15, 16; Plate 17, fig. 9; Klem, 1904, p. 66.

Spines with six ranges of spinules. These spines measure up to 54 mm. in length.

Lower Carboniferous, l'Ardoisière, France.

Archaeocidaris (?) sp. Julien.

Archaeocidaris sp. Julien, 1896, p. 127, Plate 8, fig. 1; Klem, 1904, p. 65.

Lower Carboniferous, Régnny; and in the quarries of Saint Germain-Laval, France.

Cidarites tennesseae Troost.

Cidarites tennesseae Troost, 1850, p. 59; Troost (in Miss Elvira Wood's paper, 1909), p. 108, Plate 8, figs. 2-5.

Archaeocidaris tennesseae Lovén, 1874, p. 44; Klem, 1904, p. 64; Lambert and Thiéry, 1910, p. 125.

Of this species no description is given by Troost, and it is known only from the figures given in Miss Wood's publication of Troost's Crinoids of Tennessee. The spines are smooth and a hexagonal interambulaeral plate is apparently referable to the species.

No locality nor geological formation are given.

Echinocrinus anceps T. and T. Austin.

Echinocrinus anceps (nomen nudum) T. and T. Austin, 1842, p. 111; T. and T. Austin, 1843, p. 207; Bather, 1907, p. 452.

Archaeocidaris anceps Etheridge, 1888, p. 221.

The description of this species is unrecognizable.

The locality and horizon of this species are not given.

The Austins (1843) compare *Echinocrinus anceps* with *E. pomum*. T. Austin later (1860) gave the name *Protechinus anceps* to a distinct species. As both are very little known, there is a possibility of confusing these names (p. 454).

Echinocrinus spinosus T. and T. Austin.

Echinocrinus spinosus (nomen nudum) T. and T. Austin, 1842, p. 111; T. and T. Austin, 1843, p. 207; Bather, 1907, p. 452.

Archaeocidaris spinosus Etheridge, 1888, p. 221.

The description of this species is unrecognizable.

The locality and horizon of this species are not given.

Echinocrinus striatus Eichwald.

Plate 15, fig. 16.

Echinocrinus striatus Eichwald, 1860, p. 654, Plate 33, fig. 17.

This species is quite unrecognizable. Known only from a fragmentary spine.
Dolomitic Limestone, Bogoslawsk, Ural, Russia.

Echinocrinus sp. Austin.*Echinocrinus* sp. T. Austin, 1848, p. 294.

A large species of *Echinocrinus* [= *Archaeocidaris*] is reported by Austin from the Wenlock Limestone, Silurian, of Glidden Hill, which is near Coalbrookdale, in Shropshire. There is no recognizable description, and Dr. Bather, who called my attention to the reference, knows nothing about the specimen (footnote p. 236).

Melonitiden Tornquist.*Melonitiden* Tornquist, 1897, p. 763, Plate 20, fig. 7.

A single interambulacral plate is figured by Tornquist. Genus doubtful.
Lower Carboniferous, Hunsrück, Germany.

Oligoporus (?) **minutus** Beede.

Plate 43, fig. 6.

Oligoporus (?) *minutus* Beede, 1899, p. 126, Plate 32, fig. 3; 1900, p. 49, Plate 7, fig. 3; Klem, 1904, p. 40.
Oligoporus minutus Lambert and Thiéry, 1910, p. 121.

Test spheroidal. A small specimen, apparently an internal mold, 23 mm. in diameter, has in each ambulacrum four vertical series of pore-pairs. No impressions of plates are shown, so that the character has to be gathered from the shape and pores alone. It is probably referable to the genus *Lovenechinus* which as described (p. 324) has four columns of plates and therefore four vertical series of pore-pairs at the midzone in each ambulacral area.

Deep Creek Limestone, Upper Coal Measures, northeast of Topeka, Kansas. Professor Beede informs me that the type is in the collections of the University of Kansas.

***Palaechinus** (?) **konigii** M'Coy.

Plate 29, fig. 9; Plate 31, fig. 7.

Palaechinus (?) *konigii* M'Coy, 1844, p. 172, Plate 24, figs. 1a-1c; Desor, 1858, p. 159.*Palaechinus konigii* M'Coy, 1844, [legend in pencil on] Plate 24, fig. 1¹; d'Orbigny, 1850, p. 154.*Echinus konigii* M'Coy, 1862, [legend on] Plate 24, fig. 1.¹

¹ In a copy of M'Coy's Carboniferous Limestone Fossils of Ireland, of the 1862 edition, seen at the Jermyn St. Museum, the name *Echinus konigii* is printed on the plate, as stated. Dr. Kitchin writes me that M'Coy (1862, p. 274) in the errata, referring to this figure says, "read *Palaechinus* instead of *Echinus*." In two copies of the 1844 edition, one at the British Museum and one at the Museum of Comparative Zoölogy, the name on the plate is partially erased and changed in pencil to read, "*Palaechinus konigii*." See footnotes pp. 275, 277, 280.

Palaechinus konincki [by clerical error] Dujardin and Hupé, 1862, p. 464; (non *Palaechinus konincki* Julien, 1896, p. 130, for which see the next species, *Palaechinus* (?) *regnii*; non Fraipont, 1904, p. 9, Plate 3, fig. 1); (pars) Klem, 1904, p. 33.

Palaechinus (?) *königi* Lovén, 1874, p. 41.

Xystria koenigii Pomel, 1883, p. 114.

Palaechinus koenigi Julien, 1896, p. 129.

Non *Palechinus konincki* Tornquist, 1897, p. 753, for which see *Palaechinus* (?) *regnii*.

Palaechinus königi Lambert and Thiéry, 1910, p. 119.

This species is known only from a few dissociated interambulacral plates with tubercles. It doubtless belongs in the family Palaechinidae, but nothing further can be said. It certainly has been burdened with names and various spellings. The specimen is a dark mass (not in a yellow sandstone as Miss Klem states) from the Lower Carboniferous of Rahan's Bay, Duukineeley, County Donegal, Ireland. The holotype and only known specimen is in the Griffith Collection, Science and Arts Museum, Dublin, where I saw it through the kindness of Dr. Scharff.

The fact that Dujardin and Hupé by error listed this species as *P. konincki* and that Julien described a new species as *P. konincki*, has made confusion between this and the next species to which I give a new name. *P.* (?) *königii* is the type and only species referred to *Xystria* by Pomel, who is the author of that genus.

***Palaechinus* (?) *regnii* nom. nov.**

Text-fig. 253.

Palaechinus konineki (name preoccupied) Julien, 1896, p. 130, Plate 10, fig. 20; Plate 11, fig. 27; (pars) Klem, 1904, p. 33; Fraipont, 1904, p. 9, Plate 3, fig. 1; (non *Palaechinus konincki* Dujardin and Hupé, 1862, p. 464, for which see *Palaechinus* (?) *königii*, p. 450).

Palechinus konincki Tornquist, 1897, p. 753.

On account of the confusion in the nomenclature of this species, it seemed best to give it a distinctive name as is done. As the ambulacral structure is unknown, one cannot state to which genus of the Palaechinidae this species belongs. According to Julien, the specimen is 90 mm. high and approximately 55 mm. wide. This width as given refers only to the width of the interambulacrum, not to what the whole specimen would be if complete. The adambulacral plates are pentagonal, others hexagonal, with numerous secondary tubercles, which, Julien says, on the adambulacral plates are arranged in horizontal series. Julien qualifiedly says

TEXT-FIG. 253.—*Palaechinus* (?) *regnii* nom. nov. Lower Carboniferous, Régnny, France. Natural size. After Julien, 1896, Plate 10, fig. 20, drawn from his rather indistinct photographic figure.

that there are apparently five columns of interambulacral plates, and the same number is given by Fraipont, based on his more nearly complete specimen. Julien's best figure shows a column of pentagonal adradial plates and in part smaller hexagonal plates of median columns. A large adambulacral plate measures 14 mm. in width and 8 mm. in height. Fraipont's photographic figure shows an ambulacrum which is about the width of one interambulacral plate. He does not describe the structure but as gathered from his figure it probably has two columns of primary plates, or primary and occluded plates at the mid-zone which structure would refer the species to either the genus *Palaeechinus* or *Maccoya*.

Lower Carboniferous, Régny, Neronde, Saint-Germain-Laval, central France; type in the possession of the family of the late Professor Julien. Marbre Noir de Dinant, Belgium (Fraipont).

***Palaeechinus robineti* Julien.**

Palaeechinus robineti Julien, 1896, p. 129, Plate 3, fig. 19; Lambert and Thiéry, 1910, p. 119.

Fragmentarily known. According to Julien, there are two columns of low narrow plates in an ambulacral area, each plate with two pores and 2.5 to 3 mm. wide by 1 mm. high. The ambulacrum therefore is about 5 to 6 mm. wide. The character of the ambulacrum fixes this species as belonging to *Palaeechinus* proper. Five ambulacral plates equal the height of an adambulacral. Of the interambulacrum there are pentagonal adambulacral and hexagonal median plates, but, as these are dissociated, the number of columns in an area is unknown. According to Julien, adambulacral plates are 5 mm. wide and 3 mm. high, the hexagonals 7 mm. wide by 4 mm. high. These measurements must have been taken from plates of different zones in the area, for hexagonal plates are necessarily nearly or quite the same height as adambulacral plates in the same horizontal row, and also the height given for adambulacral plates does not equal the 5 mm. which is what Julien says is the height of five ambulacrals which equal the height of an adambulacral. As the number of interambulacral columns is unknown, this species cannot be placed systematically in its relation to other species of *Palaeechinus*, and if known, it might prove to be the same as some already described species. Julien's figure is too indistinct to be recognizable.

Lower Carboniferous, La Varville, Siguret, central France. Holotype in the possession of the family of the late Professor Julien.

***Paleechinus* sp. Tornquist.**

Paleechinus sp. Tornquist, 1897, p. 763, Plate 20, fig. 6; Klem, 1906, p. 37.

A single small pentagonal adambulacral plate is figured; its genus is doubtful.
Lower Carboniferous, Hunsrück, Germany.

Palaeocidaris exilis Eichwald.

Text-fig. 254.

Palaeocidaris exilis Eichwald, 1854, p. 114, Plate 2, fig. 14.

Bothriocidaris exilis Eichwald, 1860, p. 656.

A small unrecognizable mass. In general, it is spheroidal in form, and has numerous small elevations which Eichwald considered to be tubercles.

Pentamerous Limestone, Silurian, of Talkhof, Russia.

Palaeodiscus gothicus Wyville Thomson.

Palaeodiscus gothicus Wyville Thomson, 1861, p. 118, Plate 4, fig. 8; Lambert and Thiéry, 1910, p. 117.

This species is unrecognizable.

Lower Ludlow Flags, Silurian, Leintwardine, Shropshire, England.

Palaeospatangus skiptoni Harte.

Palaeospatangus skiptoni Harte, 1869, pp. 135, 136.

Described as spatangoid in shape, but no recognizable description is given. All data are doubtful, but Harte thought that the specimen came from the Lower Carboniferous Sandstone of Scotland.

Perischodomus magnus Tornquist.

Perischodomus magnus Tornquist, 1893, p. 103; Klem, 1904, p. 20.

Described from a single interambulaeral plate which bears a primary and secondary tubercles. The status of the species is doubtful as well as its generic reference.

Lower Carboniferous, Upper Alsace, Germany.

PROTOECHINUS T. Austin.

Protoechinus T. Austin, 1860, p. 446; Lovén, 1874, p. 42; Jackson, 1896, p. 235; Klem, 1904, p. 75.

Palaeoechinus (pars) Duncanson, 1889a, p. 13.

Melonechinus (pars) Lambert and Thiéry, 1910, p. 120.

Ambulaera with two columns of plates, and passing toward the wider portion of the area with interrelated plates added, producing four columns. There is a pore-pair in each plate. The interambulaerum is fragmentarily known, and other parts of the test are unknown.

Type species, *P. anceps* Austin, from the Lower Carboniferous of Ireland.

254

TEXT-FIG. 254.—*Palaeocidaris exilis* Eichwald. Holotype. Natural size and enlarged. After Eichwald, 1854, Plate 2, fig. 14.

Protoechinus anceps T. Austin.

Protoechinus anceps T. Austin, 1860, p. 446, text-fig.; Lovén, 1874, p. 42. Klem, 1904, p. 75.

Proto Echinus ——— Baily, 1865c, p. 66.

Mcclonchinus anceps Lambert and Thiéry, 1910, p. 120.

With characters of the genus. This looks like a very interesting type, but with present knowledge cannot be definitely located. The ambulacrum passing from two columns of primary plates to four columns in an area, as figured by Austin, suggests the development of an ambulacral area as seen in the Palaeochinidæ. Two ambulacral plates equal the height of an adradial. The interambulacrum is represented only by an adradial column as figured by Austin. T. and T. Austin earlier (1842) gave the name *Echinocrinus anceps* to a distinct species; as both are very little known, there is a possibility of confusing these names (p. 449).

Lower Beds of the Carboniferous Limestone, Hook Point, County Wexford, Ireland.

Rhocchinus sp. Duncan.

Rhocchinus sp. Duncan, 1889, p. 205; Klem, 1904, p. 30.

Duncan states that the specimen is small and in the Woodwardian [now called Sedgwick] Museum at Cambridge, England. Since he used *Rhocchinus* for *Palaeochinus* as here considered (p. 303), this specimen is probably a species of *Palaeochinus*.

Rhocchinus (?) sp. Tornquist.

Rhocchinus (?) sp. Tornquist, 1897, p. 763, Plate 20, fig. 8; Klem, 1904, p. 30.

Tornquist figures only an imperfect plate. Genus quite unrecognizable, but Tornquist uses the generic name *Rhocchinus* for *Palaeochinus* as here considered (p. 303).

XENOCIDARIS Schultze.

Xenocidaris Schultze, 1866, p. 126; Lovén, 1874, p. 44; Lambert and Thiéry, 1910, p. 126.

Eocidaris (pars) Pomel, 1883, p. 113.

This genus was based on peculiar spines from the Devonian of the Eifel region, which are not even yet found in association with a test or plates. The base of the spines is known only in a specimen of *X. cylindrica* as described below. Here the spine has a milled ring and concave base for articulation with a tubercle of considerable size. The spines are doubtless referable to Echini, and quite possibly to the Cidaroida (pp. 245, 455) but as plates of the test are as yet unknown it seems safest to treat of the genus and species here.

Type species, *Xenocidaris clavigera* Schultze, from the Devonian, of Prussia.

****Xenocidaris clavigera* Schultze.**

Text-figs. 256a-256d, p. 455.

Xenocidaris clavigera Schultze, 1866, p. 126, Plate 13, figs. 3a-3h; Lovén, 1874, p. 44; Jackson, 1896, p. 222; Klem, 1904, p. 75; Lambert and Thiéry, 1910, p. 126.

Palaeocidaris rhenanus Quenstedt, 1875, p. 377, Plate 75, figs. 30-37 (figs. 30-32 are doubtful).¹

Spines are slender proximally, from this portion enlarging by a gradual tapering, or toward the distal end rapidly expanding into a trumpet-shaped form. Distally, the border and inflated terminal face are set with fluted or spinulose expansions directed distally. These spines are quite unlike anything else known in the Palaeozoic Echini, but recall some of the peculiar cidarid spines occurring in the Mesozoic. They can well be compared to such spines as those of the Jurassic *Tiaris conoideus suevicus* (Quenstedt, 1875, Plate 70, figs. 25-28) to which Quenstedt (1875, p. 377) compares them. Eleven specimens in the British Museum measure up to 31 mm. in length, and at the distal expanded tip measure up to 6 mm. in diameter.

The spines described by Quenstedt as *Palaeocidaris rhenanus* are from Eifel specimens, and his figures 33 to 37 are certainly the same species as Schultze's *Xenocidaris clavigera*. His figures 30 to 32 are doubtful, but are apparently closely allied as they have a similar club shape, but are not distally truncated with terminal spinules in a crown like the spines of *clavigera*.

Middle Devonian, Gerolstein, Prussia, Museum of Comparative Zoölogy Collection 3,044, some thirty spines, including the cotypes from the Schultze Collection; same locality, British Museum Collection E 1,269, E 398; Munich Museum; Strassburg Museum; Freiburg i. B. Museum; Kerpen, Prussia, Schultze Collection, Museum of Comparative Zoölogy 3,059.

***Xenocidaris conifera* Schlüter.**

Xenocidaris conifera Schlüter, 1881, p. 213; Klem, 1904, p. 76; Lambert and Thiéry, 1910, p. 126.

Spines smooth and conical.

Middle Devonian, Hillesheimer-Mulde, between Kerpen and Mollenbach, Germany. Professor Steinmann informs me that Schlüter's original specimen or specimens are in the collections at the museum in Bonn.

¹ See footnotes, p. 288.

TEXT-FIG. 255.—*Xenocidaris cylindrica* Schultze. Middle Devonian, Gerolstein, Eifel, Prussia. Cotype, enlarged. After Schultze, 1866, Plate 13, fig. 4b. Museum of Comparative Zoölogy Coll., 3,201.

TEXT-FIG. 256a-d.—*Xenocidaris clavigera* Schultze. Middle Devonian, Mühlenberg, near Gerolstein, Eifel, Prussia. Cotypes, enlarged. After Schultze, 1866, Plate 13, figs. 3, 3a, 3c, 3d. Museum of Comparative Zoölogy Coll., 3,044.

***Xenocidaris cylindrica** Schultze.

Text-fig. 255, p. 455.

Xenocidaris cylindrica Schultze, 1866, p. 126, Plate 13, figs. 4-4c; Lovén, 1874, p. 42; Klem, 1904, p. 76; Lambert and Thiéry, 1910, p. 126.

The spines are not cylindrical as the name implies, but spindle-shaped, thickly set with small nodose spinules, which are quite regularly spaced. A spine in the Munich Museum measures 55 mm. in length. In the British Museum there are six fragmentary spines, E 10,693 to E 10,698. One of these, E 10,693, is 28 mm. long, incomplete distally, but proximally has an expanded milled ring, which is angular in outline, with the milling nearly worn off, and resembling the base of the spines of *Archaeocidaris rossica* (Plate 12, figs. 13a-13k). The base of the spine is hollowed for articulation with a tubercle of considerable size. This specimen is important, as it is the only one I know of in the genus which shows the proximal end of the spine. The structure shows that it is typically echinoid, a fact that was not definitely known before. The character of the spines strongly suggests that of *Archaeocidaris*, but, as that genus has not yet been recorded from the Devonian, it is probably best to leave the species in its present genus, awaiting further knowledge.

Middle Devonian, Gerolstein, Prussia, cotypes (five spines) from the Schultze Collection, Museum of Comparative Zoölogy Collection 3,201; British Museum Collection E 10,693 to E 10,698; Munich Museum.

NOMINA NUDA.

Archaeocidaris tirolensis Stache, 1876, p. 260; Klem, 1904, p. 64; Lambert and Thiéry, 1910, p. 125.

No description of this species has been published.

Echinocrinus cidariformis (?) T. and T. Austin, 1842, p. 111.

No description of this species has been published.

Echinocrinus pomum T. and T. Austin, 1842, p. 111; 1843, p. 207.

The species *Echinocrinus pomum*, though not described, is discussed under the consideration of *Echinocrinus anceps* by the Austins (1843). (See p. 449.)

HETEROCIDARIS Hall; **Heterocidaris keokuk** Hall; **Heterocidaris laevispina** Hall.

Miller in his Catalogue of North American Fossils (1897, p. 747) gives the names of the genus *Heterocidaris* with the two species as listed, and attributes them to Hall's (1861) "Descriptions of New Species of Crinoidea from Investigations of the Iowa Geological Survey." Hall's paper consists of 18 pages in the copies I have seen, but there is a rumor

that a page 19 was separately printed and later issued. On inquiry at Albany and elsewhere, I can find no trace or assurance of this extra page on which I presume these names appear. Miller says that the descriptions are unrecognizable. The generic name *Heterocidaris* would not hold as it was already given to a sea-urchin by Cotteau (Bull. Soc. Géol. de France, 1860, ser. 2, vol. 7, p. 378). The specimen of *Pholidocidaris irregularis* Meek and Worthen, shown here on Plate 73, fig. 6, has pasted on the back a label, apparently in Hall's handwriting, bearing the name *Heterocidaris laevispina*. Also a tablet bearing several plates of *Pholidocidaris irregularis* in the University of Michigan Collection, here figured on Plate 74, figs. 3-7, bears in old manuscript the name *Heterocidaris laevispina*. It is therefore probable that Hall's *Heterocidaris laevispina* is the same as Meek and Worthen's *Pholidocidaris irregularis*, but, as it was inadequately described and the paper is unavailable, it is undesirable to resuscitate the name.

Messrs. Lambert and Thiéry (1910, p. 124) erroneously refer *Heterocidaris keokuk* Hall to *Archaeocidaris keokuk* Hall (this memoir, p. 267), but in their citation of page and Plate they refer to the true *Archaeocidaris keokuk* Hall, which is published in the Report on the Geological Survey of the State of Iowa, 1858, Vol. 1, Part 2, p. 699, Plate 26, figs. 2a, 2b. (By clerical error Lambert and Thiéry's bibliographical reference "956" is to Meek and Worthen, and not to Hall's work, which in their bibliography is no. "635.")

Lepidocentrus desori Dollo and Buisseret, 1888, p. 959.

No description of this species has been published.

Lepidocentrus duponti Dollo and Buisseret, 1888, p. 959.

No description of this species has been published.

Lepidocentrus gaudryi Dollo and Buisseret, 1888, p. 959.

No description of this species has been published.

Melonites youngi Young, 1878, p. 225.

Melonechinus youngi Smith, 1901, p. 509.

Young gives no description of this species of *Melonites*, but states that plates were first found in Craigenglen (Scotland) and later in other localities. Young attributed the species to Keeping, but I cannot find that Keeping ever published it. Keeping (1876, p. 399) says that Mr. J. Young had mentioned to him traces of *Melonites* in the Glasgow shales. Smith gives as localities for this species, Beith, Dobry, Muirkirk (Scotland), and says abundant but local.

Palaechinus agassizi Dollo and Buisseret, 1888, p. 959.

No description of this species has been published.

Palaechinus carpenteri Dollo and Buisseret, 1888, p. 959.

No description of this species has been published.

Palaechinus loveni Dollo and Buisseret, 1888, p. 959.

No description of this species has been published.

PALAEOZOIC FORMS INCORRECTLY REFERRED TO ECHINI.

DISCOCYSTIS Gregory, 1897, p. 131; Klem, 1904, p. 73.

Echinodiscus Worthen and Miller, 1883, p. 335, non *Echinodiscus* Leske, 1778, p. 131; Klem, 1904, p. 73.

The name *Discocystis* was given by Gregory to replace the name *Echinodiscus*, which was preoccupied.

Discocystis kaskaskiensis (Hall).

Agelacrinus kaskaskiensis Hall, 1858, p. 696, Plate 25, fig. 18.

Echinodiscus kaskaskiensis Keyes, 1894, p. 133, Plate 18, fig. 3; Klem, 1904, p. 73.

Discocystis optatus (Worthen and Miller).

Echinodiscus optatus Worthen and Miller, 1883, p. 336, Plate 31, fig. 9; Klem, 1904, p. 73.

Discocystis sampsoni (Miller).

Echinodiscus sampsoni Miller, 1891, p. 76, Plate 12, fig. 16; 1892, p. 686, Plate 12, fig. 16; Keyes, 1894, p. 133; Klem 1904, p. 73.

The above considered species referred to *Discocystis* I think are all *Cystoidea*, but they were referred doubtfully to *Echini* by Miss Klem (1904, p. 73); and the genus *Discocystis* also was qualifiedly compared to *Echini* by Gregory (1897, p. 131).

MYRIASTICHES Sollas, 1899, p. 700; Klem, 1904, p. 74; Lambert and Thiéry, 1910, p. 117. Genotype, *M. gigas* Sollas.

Myriastiches gigas Sollas, 1899, pp. 700, 701, text-fig. 5; Klem, 1904, p. 74; Lambert and Thiéry, 1910, p. 117.

Of doubtful nature; the described material is in the University Museum, Oxford.

Palaechinus sp. Mitchell, 1897, p. 258, text-fig.; Klem, 1904, p. 36.

Of doubtful nature; Silurian, New South Wales.

SPATANGOPSIS Torell, 1869, p. 11; Klem, 1904, p. 75. Genotype, *S. costata* Torell.

Spatangopsis costata Torell, 1869, p. 11; Zittel, 1879, p. 480; Klem, 1904, p. 75.

The genus *Spatangopsis* is not an echinoid, but a medusoid according to Zittel (*Grundzüge der Palaeontologie*, p. 111) and other authorities.

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INDEX.

The index includes all scientific names of sea-urchins or other animals, occurring in this memoir. The accepted names are in Roman type, excepting new ones, which are in heavy-faced type. All synonyms or exceptional spellings are in italics. Personal names are included in the index only where there is discussion of opinions or other special need of comment. The names of those from whom material was borrowed or to whom I am otherwise under obligations are given in the Introduction, as well as throughout the text but are not included in the index. The page-references in heavy faced type indicate the more important pages on which the case in hand is described.

- abyssicola, *Cidaris*, 96, 100.
 acanthifera, *Archaeocidaris*, 237, 258, **272**.
Acanthocidaris hastigera, 97.
Acrosalenia, 78, 112, 214.
 aspera, 112, 157.
 decorata, 112, 157.
 hemicidaroides, 111, 112, 113, 157, 164, 174.
 pseudodecorata, 112, 148, 150, 152.
 pustulata, 112, 157, 164.
 spinosa, 111, 112, 157, 174, 175.
 wiltoni, 111, 112, 157, 175, 176.
acuaria, *Echinocystis*, 441.
 Eocidaris, 441.
acuaria, *Pholidocidaris*, 236, 443, **441**.
acuaria, *Protocidaris*, 441.
aculeata, *Archaeocidaris*, 237, 238, 258, **268**.
aculeatus, *Archaeocidaris*, 268.
acutus, *Echinus*, 118, 139, 160.
affinis, *Cidaris*, 61, 91, 92, 95, 96, 97, 99, 100, 141, 146.
 Echinus, 117, 118, 139, 150, 153, 160, 171, 216.
 Agassiz, Alexander, 10, 11, 18, 28, 31, 32, 33, 34, 52, 56, 57, 61, 63, 64, 65, 69, 71, 74, 79, 81, 82, 84, 85, 86, 88, 89, 101, 102, 104, 110, 111, 113, 116, 117, 121, 127, 128, 167, 168, 170, 174, 175, 176, 177, 185, 187, 189, 198, 210, 214, 215, 217, 218, 219, 223, 287, 297, 361, 362, 363, 378, 395, 398, 413, 414, 415, 433.
 Agassiz, Alexander, and Clark, H. L., 28, 62, 76, 82, 97, 104, 118, 128, 172, 213, 215, 218, 415.
 Agassiz, Louis, 15, 33, 257, 400.
agassizi, *Archaeocidaris*, 82, 237, 256, 258, **266**.
 Palaechinus, 305, **457**.
agassizii, *Archaeocidaris*, 266.
Agelacrinus kaskaskiensis, 458.
albida, *Trigonocidaris*, 159.
albus, *Strongylocentrotus*, 95, 127, 162, 164, 217.
Aldrovandus, *Ulysses*, 10, 244.
alexandri, *Salmacis*, 159.
Amblypneustes, 35, 50, 187.
 formosus, 31, 159.
 griscus, 159.
 ovum, 159.
 pallidus, 159.
Ammonites, 56, 232.
Anadema, 28.
Ananchytes, 52, 92, 150.
 ovatus, 112, 148.
anceps, *Archaeocidaris*, 449.
anceps, *Echinoerinus*, 258, **449**, 454, 456.
anceps, *Melonechinus*, 454.
anceps, *Protoechinus*, 449, 453, **454**.
anglicus, **Lovenechinus**, 304, 321, 326, **346**.
angulosus, *Echinus*, 119, 151, 153, 160, 164.
annelata, *Calmarinus*, 28.
annulatus, *Microcyphus*, 166.
annulifera, *Phyllacanthus*, 101, 102, 150, 152, 153.
antarcticus, *Sterechinus*, 120.
Antedon, 52.
 rosaceus, 52.
antillarum, *Dermatodiadema*, 81, 104, 154.
antillarum, *Diadema*, 28.
Arachnoides, 64, 72, 204, 218.
 placenta, 72.
Arbacia, 18, 19, 29, 40, 46, 52, 58, 62, 65, 69, 71, 73, 87, 89, 90, 91, 107, 116, 167, 175, 176, 183, 187, 189, 192, 194, 198, 210, 215, 217, 241.
 dufresni, 115, 158, 164, 176.
 lixula, 40, 47, 79, 114, 158, 164, 187, 192, 194, 195.
 nigra, 95, 114, 115, 148, 150, 152, 153, 158, 164, 170, 187, 192, 194, 195.
 punctulata, 35, 37, 39, 41, 42, 44, 45, 46, 48, 50, 88, 114, 115, 141, 151, 152, 153, 158, 164, 170, 171, 175, 176, 179, 185, 187.
 spatuligera, 95, 115, 116, 158, 164.
 stellata, 114, 158.
Arbaciidae, 92, 93, 111, 113, 116, 133, 146, 150, 158, **203**, 209, 214, 215, 218.
Archaeocidaridae, 70, 89, **206**, 209, 223, 236, **254**, 284, 302, 305, 379, 393, 409.
Archaeocidaris, 10, 18, 23, 29, 32, 54, 70, 73, 74, 77, 78, 82, 85, 178, 181, 182, **206**, 209, 212, 223, 224, 236, 237, 238, 254, 255, **256**, 261, 270, 275, 277, 278, 280, 282, 283, 289, 307, 361, 363, 395, 407, 413, 414, 450, 456.
acanthifera, 237, 258, **272**.
aculeata, 237, 238, 258, **268**.
aculeatus, 268.
agassizi, 82, 237, 256, 258, **266**.
agassizii, 266.
anceps, 449.
benburbensis, 277.
biangulata, 237, 258, **273**.
biangulatus, 273.
clavata, 259, **282**.

Archaeocidaris (continued).

- coloradensis**, 237, 258, **267**, 274.
cratis, 237, 258, **272**.
dininni, 271.
dininnii, 237, 258, **271**.
drydenensis, 288.
edgarensis, 237, 258, **269**.
elegans, 280.
forbesiana, 238, 257, 259, **280**.
glabrispina, 258, **261**.
gracilis, 237, 258, **267**.
gruneri, 277, 279.
halliana, 237, 259, **279**.
hallianus, 279.
harteiana, 408.
illinoisensis, 258, **266**.
keokuk, 258, 259, **267**, 457.
konincki, 258, **446**.
ladina, 258, **446**.
laevis, 262.
legrandensis, 256, 258, **260**.
longispina, 237, 258, **261**.
megastyla, 237, 258, **273**.
megastylis, 273.
megastylus, 273.
mucronata, 258, 267, **271**, 272, 274.
mucronatus, 271.
muensteriana, 259, **280**, 442.
münsteriana, 280.
münsterianus, 280.
nerci, 258, **262**.
nerii, 262.
newberryi, 258, **269**.
norwoodi, 258, **270**.
ornata, 258, 267, 271, **274**.
ornatus, 267, 271, 274.
ourayensis, 237, 258, **274**.
paradoxa, 237, 258, **270**.
pizzulana, 258, **272**.
prisca, 11, 259, **276**.
priscus, 276.
protei, 262, 263.
rankini, 11, 259, **276**, 449.
regimontana, 277, 279.
rossica, 77, 82, 177, 184, 224, 255, 256, 258, **263**, 456.
rossica var. *schellwici*, 263, 264.
rossicus, 263.
scotica, 258, **447**.
selwyni, 238, 258, **447**.
shumardana, 258, **268**.
shumardanus, 268.
shumardi, 268.
shumardiana, 268.
shumardina, 268.
sixi, 258, **447**.
sp., 269, 272, 281, 447, 408, **448**, **449**.
sp. a., 272.
sp. b., 237, 259, **281**.
sp. b. var., 281, 282.

Archaeocidaris (continued).

- sp. c.*, 281, 282.
sp. d., 281, 282.
spinoclavata, 237, 259, **281**.
spinoclavatus, 281.
spinosus, 449.
stellifera, 261, 262.
tennesseae, 449.
tirolensis, 258, **456**.
trautscholdi, 258, **448**.
triplex, 237, 258, **274**.
triserata, 275.
triserialis, 258, **275**.
triserrata, 237, 258, **275**.
triserratus, 275.
trudifer, 237, 258, **269**.
trudifera, 270.
urei, 277.
urii, 82, 256, 257, 259, **276**.
verneuilliana, 245, 268.
vetusta, 277, 279.
vetustus, 277.
wervekei, 259, **276**.
wervekei, 276.
wortheni, 70, 81, 82, 224, 256, 257, 258, **259**, 264, 267.
archaica, **Bothriocidaris**, 28, 34, 42, 45, 48, 52, 53, 54, 62, 64, 69, 70, 79, 81, 87, 88, 148, 167, 173, 210, **239**, 242, 243, 244, 446.
aspera, *Acrosalenia*, 112, 157.
Aspidodiadema, 33.
mcijerci, 154.
nicobaricum, 152, 153, 154.
Aspidodiadematidae, 87, 104, 154, **202**, 209, 213.
Asterias, 52.
asteriscus, *Centrostephanus*, 109, 156.
Asterocidaris minor, 103, 154.
Asteroidca, 200, 222.
Asthenosoma, 62, 81, 168, 179, 186, 195.
hystrix, 156.
ijimai, 109, 110, 156.
owstoni, 156.
Astropyga, 56, 74, 109, 110, 174, 189, 202, 213, 214.
pulvinata, 74, 76, 109, 156.
radiata, 156.
atlanticus, *Leptechinus*, 121.
atlanticus, *Toxopneustes*, 35, 36, 41, 44, 46, **121**, 122, 141, 151, 153, 161, 164, 166, 170.
atratus, *Colobocentrotus*, 35, 45, 147, 163, 217.
Aulodonta, 103, 110, 154, 155, 156, 174, 178, **183**, 186, 187, **202**, 209, 212, 214, 220, 221.
Austin, Thomas, 236, 449, 450, 454.
Austin, Thomas, and Thomas, Jr., 449, 454, 456.
Baculites, 56.
baculosa, *Phyllacanthus*, 99, 101, 102, 148, 150, 152, 153, 192, 194.
Baily, W. H., 10, 89, 262, 303, 306, 307, 308, 309, 310, 318, 319, 321, 322, 332, 363, 403, 407, 408, 409, 414, 419.

- Bateson, William, 35, 50.
 Bather, F. A., 11, 27, 29, 73, 74, 88, 96, 172, 190, 208, 220, 223, 236, 242, 245, 246, 247, 254, 255, 257, 277, 318, 327, 330-334, 387, 450.
 Beecher, C. E., 71, 293, 295, 298, 299.
beecheri, Hyattechinus, 12, 16, 17, 22, 25, 28, 32, 34, 64, 65, 67, 173, 210, 225, 226, 237, 292, 293, 297.
 Beede, J. W., 266, 270, 273, 446, 450.
 Bell, F. J., 175, 195.
bellulus, Oligoporus, 351, 352.
benburbensis, Archacocidaris, 277.
Cidaris, 277, 278, 279.
 Beyrich, Ernst, 288.
biangulata, Archacocidaris, 237, 258, 273.
biangulata, Cidarotropus, 273.
biangulatus, Archacocidaris, 273.
bicolor, Salmacis, 159.
bigranularis, Stomechinus, 104, 105, 155.
biscralis, Goniocidaris, 100, 102.
Perischodomus, 64, 70, 76, 233, 237, 309, 401, 411.
bisserialis, Perischodomus, 401.
blairi, Eocidaris, 260, 261.
blairi, Oligoporus, 304, 351, 354, 355.
Bothriocidaridac, 201, 209, 238.
Bothriocidaris, 10, 12, 23, 31, 34, 46, 53, 57, 58, 64, 65, 69, 71, 72, 78, 79, 82, 83, 85, 87, 88, 89, 167, 174, 181, 201, 208, 209, 210, 211, 219, 220, 235, 238, 240, 244, 254, 295, 378, 405, 439, 444.
archaica, 28, 34, 42, 45, 48, 52, 53, 54, 62, 64, 69, 70, 79, 81, 87, 88, 148, 167, 173, 210, 239, 242, 243, 244, 446.
exilis, 453.
globulus, 10, 34, 87, 88, 210, 239, 240, 243.
pahleni, 34, 69, 77, 87, 88, 167, 210, 239, 240, 242, 244.
pahleni, 242.
phaleni, 242.
Bothriocidaroida, 201, 209, 211, 238.
Botriocidaris, 238.
globulus, 243.
pahleni, 242.
Botryocidaris, 238.
pahleni, 242.
 Brachiopoda, 71.
brauni, Pholidechinus, 184, 226, 237, 265, 295.
Brisaster fragilis, 177.
 Brissus, 219.
 Buisseret, A. See Dollo, Louis, and Buisseret, A.
burlingtonensis, Maccoya, 54, 55, 59, 60, 227, 229, 230, 231, 300, 303, 312, 314, 315.
burlingtonensis, Palaechinus, 303, 312.
Palaechinus, 303, 313.
Rhoechinus, 313, 323.
 Bury, Henry, 210.
 Calamaria, 28.
calamaria, Diadema, 28.
ealamaris, Echinothrix, 28, 109, 155.
Calamarius, 28.
caledonica, Lepidesthes, 416, 432.
Calmarius, 28.
annelata, 28.
Camarodonta, 30, 116, 159, 160, 161, 162, 163, 179, 183, 186, 187, 203, 209, 214, 215.
canaliculata, Goniocidaris, 54, 70, 81, 99, 100, 101, 102, 170, 184.
candidum, Diadema, 27.
 Cannon, G. L., 247, 249.
cannoni, Miocidaris, 212, 236, 238, 245, 247, 257.
carinata, Lepidesthes, 408, 412, 416, 424.
carpenteri, Palaechinus, 305, 458.
cartieri, Hemicidaris, 154.
Caryocrinus, 35.
cassiana, Miocidaris, 245.
Cassidulus, 92, 150.
subquadratus, 148.
Centrechinidae, 28, 74, 76, 78, 92, 93, 104, 105, 108, 109, 110, 155, 156, 202, 209, 213.
Centrechinoida, 27, 28, 30, 55, 59, 60, 61, 62, 64, 78, 79, 83, 84, 85, 87, 91, 92, 93, 94, 95, 96, 102, 103, 109, 113, 116, 129, 133, 146, 152, 154-164, 174, 178, 182, 183, 186, 187, 188, 189, 192, 194, 196, 198, 200, 202, 208, 209, 211, 212, 213, 215, 217, 218, 219, 220, 221, 223, 361, 413, 414.
Centrechinus, 16, 19, 28, 54, 56, 63, 74, 76, 85, 91, 94, 104, 106, 107, 108, 110, 172, 174, 183, 190, 194, 195.
setosus, 28, 76, 104-109, 110, 152, 153, 155, 164, 167, 168, 170, 183, 185, 191, 192, 213.
Centrostephanus, 174.
asteriscus, 109, 156.
longispinus, 108, 110, 156.
rogersi, 108, 110, 152, 153, 156.
 Cephalopoda, 16, 17, 66, 220.
 Chadwick, H. C., 35, 179.
Chaetodiadema, 76, 109, 110, 174.
pallidum, 108, 110, 156.
chilensis, Fabia, 145.
chloroticus, Evechinus, 125, 161, 164.
Cidaridae, 55, 60, 64, 62, 78, 79, 84, 82, 87, 88, 95, 100, 101, 103, 172, 192, 195, 201, 209, 211, 236, 240, 245, 248, 257, 320, 332, 413.
Cidarids, 69, 71, 77, 83, 89, 102, 106, 109, 112, 173, 174, 190, 211, 212, 213, 226, 248, 249, 265, 309, 312, 445, 455.
cidariformis, Echinoecrinus, 258, 456.
Cidaris, 17, 29, 32, 34, 51, 52, 55, 58, 64, 65, 66, 73, 82, 83, 86, 96, 179, 182, 190, 192, 214, 221, 260, 277, 445.
abyssicola, 96, 100.
affinis, 61, 91, 92, 95, 96, 97, 99, 100, 141, 146.
benburbensis, 277, 278, 279.
cidaris, 96, 100, 182.
coronata, 95, 96, 100, 148.
deucalionis, 263.
elegans, 280.
florigemma, 95.
forbesiana, 280.
glabrispina, 261.
keyserlingi, 245.
klipsteini, 245.

- Cidaris* (*continued*).
laevispina, 255, 256.
muensterianus, 280.
munsteriana, 280.
neret, 262.
panamensis, 34.
papillata, 61, 182.
rossicus, 263.
sceptifera, 95.
scrobiculata, 255, 256.
urii, 276, 277.
verneuilliana, 245.
victusta, 277, 278, 279.
cidaris, *Cidaris*, **96**, 100, 182.
cidaris, *Echinus*, 96.
Cidarites muensterianus, 280.
neret, 262.
priscus, 276, 274.
protei, 262.
rossicus, 263.
tennesseae, 258, **449**.
Cidaroida, 29, 78, 79, 91, 92, 93, 94, 95, 100, 101, 102, 103, 116, 123, 125, 146, 152, 174, 178, 181, 182, 183, 186, 188, 192, 194, 196, 200, **201**, 209, 211, 212, 213, 214, 217, 220, 221, 223, 227, 238, **244**, 245, 249, 379, 454.
Cidarotropus, 256, 257.
biangulata, 273.
hallianus, 279.
megastylus, 273.
norwoodi, 270.
pizzulana, 272.
rossica, 263.
trauscholdi, 448.
wortheni, 259.
cincta, *Salenia*, 112, 157.
cinctus, *Plexechinus*, 70.
Cirrhopoda, 28.
Cirriped, 27.
Clark, A. H., 200.
Clark, H. L., 39, 92, 96, 116.
Clark, H. L. See Agassiz, Alexander, and Clark, H. L.
clarki, *Salenia*, 111.
clavata, *Archaeocidaris*, 259, **282**.
clavatus, *Echinocrinus*, 282.
clavigera, *Xenocidaris*, 288, 454, **455**.
Clypeaster, 18, 25, 53, 73, 74, 78, 188.
rosaceus, 73, 185, 196, 197.
subdepressus, 196, 197.
Clypeastrina, 29, 188, 189, 196, 197, 198, **204**, 209, 217, 218.
Clypeastroids, 18, 26, 29, 32, 53, 56, 62, 65, 69, 70, 71, 72, 73, 74, 78, 85, 167, 179, 180, 196, 200, 210, 218.
cobosi, *Porocidaris*, 34, 61, 89, 414.
Coelopleurus floridanus, 116, 158.
colletti, *Lepidesthes*, 28, 31, 34, 53, 54, 59, 75, 172, 174, 234, 416, 420, **425**, 431, 443.
Collyrites, 33, 56, 69, 72, 86.
Colobocentrotus, 45, 77, 187, 217.
atratus, 35, 45, 147, 163, 217.
coloradensis, *Archaeocidaris*, 237, 258, **267**, 274.
conifera, *Xenocidaris*, **455**.
conoideus suevicus, *Tiaris*, 455.
Conolampas sigsbei, 198.
corallinus, *Pelanechinus*, 444.
coranguineum, *Micraster*, 54, 148.
coreyi, *Lepidesthes*, 25, 32, 415, **423**, 424.
Oligoporus, 304, 351, **353**, 355.
coronata, *Cidaris*, 95, 96, 100, 148.
Coronula diadema, 27.
corveyi, *Lepidesthes*, 423.
costata, *Spatangopsis*, **458**.
Cottaldia, 104.
granulosa, 155.
Cotteau, Gustave, 112, 152, 457.
cotteau, *Koninekocidaris*, 11, 224, 225, 237, 284, **285**, 286.
cotteau, *Lepidochinus*, 285.
[cotteau], *Perischodomus*, 285.
crassus, *Melonechinus*, 364, **367**.
crassus, *Melonites*, 367.
cratis, *Archaeocidaris*, 237, 258, **272**.
crenularc, *Glyptocidaris*, 113, 186, 214, 215.
crenulare, *Phymosoma*, 112, 186.
crenularis, *Hemiecidaris*, 103, 154, 164.
Crinoidea, 200, 362.
Crinoids, 16, 35, 200, 362.
cylindrica, *Discoidea*, 189.
Xenocidaris, 454, 455, **456**.
Cystechinus, 219.
Cysticaroidea, 250.
Cystocidaridae, 250.
Cystocidaris, 250, 252.
pomum, 252.
uwa, 252.
Cystocidaroida, 250.
Cystoidca, 200, 458.
Cystoids, 35.
Dalmanites limulurus, 286.
danae, *Melonites*, 356.
[danae], *Melionopsis*, 356.
danae, *Oligoporus*, 54, 228, 229, 230, 231, 304, 335, 350, 351, 353, **356**, 491.
danae, *Palaechinus*, 356.
Day, George, 249.
decorata, *Acrosalenia*, 112, 157.
dclamarei, *Phymosoma*, 113, 158.
dentata, *Rotula*, 70.
depressus, *Strongylocentrotus*, 129, 162.
Tripneustes, 123, 161.
Dermatodiadema, 84, 85, 398.
antillarum, 81, 104, 154.
horridum, 154.
Desor, Edouard, 10, 262, 263, 265.
desori, *Diplocidaris*, 95, 96, 101.
Lepidocentrus, 287, **457**.
deucalionis, *Cidaris*, 263.
Echinocrinus, 263.
devonicans, *Lepidesthes*, 236, 415, **420**, 432.

- Diadema*, 27, 28.
 antillarum, 28.
 calamari, 28.
 candidum, 27.
 scotum, 28, 104.
 vulgaris, 27.
diadema, *Coronula*, 27.
 Echinothrix, 109, 155.
diadema, *Lepas*, 27.
diadema, *Sterechinus*, 120.
dininni, *Archaeocidar*, 271.
dininnii, *Archaeocidar*, 237, 258, 271.
Diplocidar, 60.
 desori, 95, 96, 101.
 gigantea, 101.
diploporum, *Laganum*, 218.
Discocystis, 458.
 kaskaskiensis, 458.
 optatus, 458.
 sampsoni, 458.
Discoidea, 188, 189, 195.
 cylindrica, 189.
dispar, *Melonechinus*, 364, 365.
dispar, *Melonites*, 365.
 Palaeocchinus, 365.
 Palechinus, 365.
 Palechthinus, 365.
Döderlein, Ludwig, 85, 119, 215.
döderleini, *Pleurechinus*, 84, 216.
Dollo, Louis, and Buisseret, A., 285.
Dorocidar, *panamensis*, 34.
 papillata, 96.
dröbachiensis, *Strongylocentrotus*, 32, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 47, 48, 49, 52, 54, 55, 78, 81, 83, 88, 90, 91, 126, 127, 128, 129-143, 151, 152, 153, 162, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 176, 177-179, 181, 192, 195.
drydenensis, *Archaeocidar*, 288.
 Echinus, 288.
 Eocidar, 288.
drydenensis, *Lepidocentrus*, 236, 287, 288.
dufresni, *Arbacia*, 115, 158, 164, 176.
Dujardin, M. F., and Hupé, M. H., 451.
Duncan, P. M., 10, 11, 28, 55, 185, 186, 190, 194, 208, 213, 214, 216, 223, 287, 303, 305, 307, 308, 312, 316, 319, 320, 321, 326, 328, 329, 346, 394, 396, 422, 454.
duponti, *Lepidocentrus*, 287, 467.

Echinarachnius, 29, 32, 64, 71, 73, 85, 292.
 parma, 35, 49, 54, 56, 58, 81, 179, 189, 196, 197.
Echinidae, 85, 92, 93, 109, 113, 117, 120, 125, 126, 127, 146, 160, 161, 167, 168, 170, 173, 174, 176, 179, 187, 203, 209, 215, 216, 217.
Echinids, 88, 378.
Echinocardium, 85.
 flavescens, 81.
Echinocrinoidea, 254.
Echinocrinus, 236, 254, 256, 257, 275, 277, 450.
 anceps, 258, 449, 454, 456.

Echinocrinus (continued).
 cidariformis, 258, 456.
 clavatus, 282.
 deucalionis, 263.
 ellipticus, 307.
 glabrispina, 261.
 munsterianus, 280.
 nerei, 262.
 ornatus, 267, 271, 274.
 pomum, 258, 449, 456.
 prisca, 276.
 priscus, 276.
 prolei, 262.
 rossica, 263.
 sp., 450.
 spinatus, 258, 449.
 striatus, 258, 450.
 triserialis, 275.
 urii, 277.
 vetustus, 277.
Echinocyamus, 172, 219.
 pusillus, 70.
Echinocystidae, 205, 209, 222, 252.
Echinocystis, 252, 432, 442.
 acuaria, 441.
 pomum, 252.
 uva, 252.
Echinocystites, 10, 28, 32, 54, 209, 250, 252, 442, 491.
 pomum, 34, 172, 222, 236, 252.
 uva, 252.
Echinocystoida, 29, 89, 181, 182, 186, 188, 196, 205, 209, 211, 220, 221, 236, 250.
Echinodermata, 77, 200.
Echinodiscus, 458.
 kaskaskiensis, 458.
 optatus, 458.
 sampsoni, 458.
Echinoidea, 55, 198, 201, 209.
Echinometra, 32, 91, 146, 187, 194.
 lucunter, 35, 39, 91, 141, 146, 147, 150, 151, 153, 163, 164, 192, 195, 217.
 mathaei, 146, 147, 151, 153, 163, 164.
 oblonga, 146, 163.
 vanbrunti, 146, 147, 151, 153, 163.
 viridis, 146, 163.
Echinometridae, 30, 87, 92, 93, 111, 113, 118, 126, 146, 147, 163, 176, 179, 186, 187, 204, 209, 214, 215, 217, 297.
Echinoneus, 189, 198, 217, 219.
Echinosigra paradoxa, 72.
Echinosoma hispidum, 34, 57, 185.
Echinosphaerites, 35.
Echinostrephus, 204, 216.
 molare, 32.
Echinothrix, 108.
 calamari, 28, 109, 155.
 diadema, 109, 155.
Echinothuridae, 413.
Echinothuriidae, 378, 413.
Echinothuriid, 62, 63, 74, 170, 181, 200, 213, 293.

- Echinothuriidae, 17, 30, 63, 64, 74, 76, 83, 109, 110, 156, 168, 177, 185, 189, **202**, 209, 212, 213, 214, 286, 287, 413, 414, 415, 433.
- Echinus, 18, 19, 27, 56, 65, 71, 87, 90, 117, 118, 120, 125, 174, 176, 179, 187, 276, 450.
 acutus, 118, 139, 160.
 affinis, 117, 118, 139, 150, 153, 160, 171, 216.
 angulosus, 119, 151, 153, 160, 164.
 cidaris, 96.
 drydenensis, 288.
 elegans, 118, 160.
 esculentus, 27, 35, 44, 117, 118, 119, 148, 151, 153, 160.
 gracilis, 118, 160.
 koenigii, 450.
 magellanicus, 35, 40, 43, 84, 119, 120, 125, 148, 151, 153, 160, 164.
 margaritaceus, 119, 160, 164.
 melo, 118, 160.
 microtuberculatus, 118, 160, 164, 210.
 miliaris, 118, 160.
 neumayeri, 119.
 verruculatus, 120.
- Ectobranchiata, 208.
- Ectobranchiates, 86.
- edgarensis, Archaeocidaris, 237, 258, **269**.
- Eichwald, Edouard von, 243, 244, 270, 365, 453.
- eifelianus, Lepidocentrus, 236, 287, **291**.
- elegans, Archaeocidaris, 280.
 Cidaris, 280.
- elegans, Echinus, 118, 160.
- elegans, Meekchinus**, 12, 28, 34, 61, 89, 172, 174, 234, 238, 265, 374, 417, 425, 430, **443**.
- elegans, Palaeochinus, 308, 332.
- elegans, Palaeochinus, 54, 59, 89, 229, 230, 231, 303, 305, **308**, 403, 414, 420.
- elegans, Rhoechinus, 303, 308, 314.
- ellipticus, Echinocrinus, 307.
 Maccoya, 307, 326.
 Palaeochinus, 305, 307, 326, 329.
- ellipticus, Palaeochinus, 31, 303, 305, 306, **307**, 308, 326, 329.
- ellipticus, Palaeocidaris, 307.
 Paleochinus, 307, 326.
- Eocidaris, **206**, 209, 223, 245, **254**, 261, 265, 454.
 acuaria, 441.
 blairi, 260, 261.
 drydenensis, 288.
 forbesiana, 280.
 forbesianus, 280.
 hallanus, 279.
 halliana, 279.
 hallianus, 279.
 kaiserlingi, 245, 246.
 keyserlingi, 246.
 konincki, 446.
 laevispina, 223, 236, **255**.
 munsterianus, 280.
 munsteri, 280.
- Eocidaris (continued).
 munsterianus, 280.
 rossica, 263.
 rossicus, 263.
 scrobiculata, 255.
 squamosa, 282.
 squamosus, 282.
 verneuiliana, 246, 247.
 verneuilianus, 246.
 verneulli, 246.
- Eotiaris, 245.
 keyserlingi, 246.
- Eriechinus, 303, 311, 312, 326.
 sphaericus, 317, 326.
- esculentus, Echinus, 27, 35, 44, 117, 118, 119, 148, 151, 153, 160.
 Tripneustes, 35, 44, 46, 48, 91, 93, 123, 124, 125, 141, 151, 153, 161, 164, 167, 168, 169, 185, 187.
- Etheridge, Robert, Jr., 447, 448.
- etheridgei, Melonechinus, 385.
- etheridgii, Melonechinus, 364, 384, **385**.
- etheridgii, Melonites, 385.
- Eucidaris, 53, 54, 58, 63, 70, 76, 77, 82, 85, 86, 87, 88, **96**, 183, 190, 192, 241, 293, 297, 372.
 metularia, 97, 100.
 thouarsi, 62, 97, 100.
- tribuloides, 35, 45, 54, 58, 61, 62, 70, 75, 81, 82, 92, 96, 97, 98, 99, 100, 102, 146, 152, 153, 167, 171, 174, 182, 184, 191, 192, 248, 249, 445.
- Euëchinoida, 211, 234.
- eurythrogrammus, Strongylocentrotus, 35, 44, 141, 144, 162.
- Evëchinus chloroticus, 125, 161, 164.
- exilis, Bothriocidaris, 453.
- exilis, Palaeocidaris, **453**.
- Exocycloida, 85, 87, 92, 177, 200, 201, **204**, 208, 209, 211, 217, 218, 220.
- extremis, Lepidesthes**, 12, 237, 416, 418, 421, **430**, 443.
- Fabia chilensis, 145.
- ferox, Palaeodiscus, 222, 236, **250**.
- flavescens, Echinocardium, 81.
- floridanus, Coelopleurus, 116, 158.
- florigemma, Cidaris, 95.
- Forbes, Edward, 316.
- forbesi, Lovenia, 72.
- forbesi, Permocidaris, 280.
- forbesiana, Archaeocidaris, 238, 257, 259, **280**.
- forbesiana, Cidaris, 280.
 Eocidaris, 280.
 Permocidaris, 280.
- forbesianus, Eocidaris, 280.
- formosa, Lepidesthes, 28, 34, 89, 172, 174, 234, 394, 415, **418**, 423, 426, 427.
- forinosus, Amblypneustes, 31, 159.
- formosus, Lepidesthes, 418.
- fragilis, Brisaster, 177.
- fragilis, (Schizaster), 177.
- fragilis, Strongylocentrotus**, 128, 151, 153, 162.

- Fraipont, Julien, 10, 233, 276, 309, 310, 327, 334, 335, 410, 411, 412, 452.
- franciscanus, Strongylocentrotus, 60, 142, 144, 148, 150, 162, 164, 171.
- Galerites, 35, 50, 195.
- gaudryi, Lepidocentrus, 287, **457**.
- gaudryi, Melonites, 442.
- gaudryi, Pholidocidaris, 11, 237, 280, 433, **442**.
- Geinitz, H. B., 246, 279.
- Genocidaris, 176.
- gibbosus, Strongylocentrotus, 94, 95, 97, 109, 120, 128, 145, 146, 152, 162, 164, 177, 217.
- gigantea, Diplocidaris, 101.
- giganteum, Sperosoma, 118.
- giganteus, Melonechinus, 16, 17, 21, 60, 61, 68, 230, 231, 361, 362, 364, 377, **389**.
- giganteus, Melonites, 389.
- Oligoporus*, 410.
- giganteus, Proterocidaris, 233, 237, 409, **410**.
- gigas, *Mac Coya*, 321.
- gigas, Maccoya, 303, 312, **321**, 346.
- Myriastiches*, **458**.
- gigas, *Palaechinus*, 304, 321, 332, 346.
- Palaechinus*, 303, 304, 321, 346.
- Palechinus*, 321, 346.
- Giles, A. W., 286.
- Girty, G. H., 249, 272, 281, 282, 337.
- glabrispina, Archaeocidaris, 258, **261**.
- glabrispina, Cidaridaris, 261.
- Echinocrinus*, 261.
- globula, Mespilia, 159.
- globulus, Bothriocidaris, 10, 34, 87, 88, 210, 239, 240, **243**.
- globulus, Botriocidaris, 243.
- Glyphocyphus radiatus, 117, 159, 216.
- Glypticus hieroglyphicus, 103, 154.
- Glyptocidaris, 113, 183.
- crenularis, 113, 186, 214, 215.
- Goniocidaris, 20, 33, 54, 57, 58, 65, 69, 70, 174, 181, 182, 210.
- biserialis, 100, 102.
- canaliculata, 54, 70, 81, 99, 100, 101, 102, 170, 184.
- nutrix, 99, 100, 101, 102, 170.
- tubaria, 100, 101.
- Goniopygus peltatus, 103, 154.
- gothicus, Palaeodiscus, 250, **453**.
- gracilis, Archaeocidaris, 237, 258, **267**.
- Echinus, 118, 160.
- gracilis, *Leptechinus*, 291.
- gracilis, Maccoya, 303, 312, **323**.
- gracilis, *Palaechinus*, 303, 323.
- Palaechinus*, 303, 323.
- Perischodomus*, 291.
- Rhoechinus*, 323.
- gracilis, Tornquistellus, 237, **291**.
- granularis, Sphaerechinus, 93, 126, 141, 162, 164, 179.
- Stomechinus, 155.
- granulatus, Melonites, 289, 392.
- granulosa, Cottaldia, 155.
- gratians, Parasalenia, 176.
- Gregory, J. W., 211, 217, 222, 243, 250, 251, 252, 253, 458.
- Griffith, Richard, 277.
- grimaldi, Sperosoma, 415.
- griseus, Amblypneustes, 159.
- Groom, T. T., 61, 444.
- gruneri, *Archaeocidaris*, 277, 279.
- Gurley, W. F. E. See Miller, S. A., and Gurley, W. F. E.
- Gymnechinus, 97, 119, 120, 145, 216.
- pulchellus, 93, 94, 120, 123, 133, 152, 160, 164, 165, 166.
- robillardii, 93, 94, 120, 160, 164, 165, 166.
- Habrocidaris, 176, 215.
- scutata, 172, 175.
- Hall, James, 10, 225, 290, 294, 356, 395, 400, 456, 457.
- hallanus, Eocidaris, 279.
- halli, *Oligoporus*, 304, 351, **355**.
- halliana, Archaeocidaris, 237, 259, **279**.
- halliana, Eocidaris, 279.
- hallianus, *Archaeocidaris*, 279.
- Cidarotropus*, 279.
- Eocidaris*, 279.
- Hambach, Gustavus, 365, 368, 380.
- hardwickii, Temnopleurus, 159.
- Harte, William, 407, 408, 409, 453.
- harlei, *Perischocidaris*, 408.
- Perischodomus*, 408.
- harteiana, *Archaeocidaris*, 408.
- harteiana, *Perischocidaris*, 10, 233, 237, 407, **408**, 424, 491.
- harteiana, *Perischodomus*, 491.
- harteianiana, *Prosechinus*, 408.
- hartii, *Homoloechus*, 408.
- hastigera, Acanthocidaris, 97.
- Hawkins, H. L., 35, 188, 189, 218.
- Heliaster, 35.
- Hemicidaridae, 92, 103, 154, **202**, 208, 209, 212.
- Hemicidaris, 17, 56, 208, 213.
- cartieri, 154.
- crenularis, 103, 154, 164.
- hoffmanni, 154.
- intermedia, 103, 154.
- langrunensis, 103, 154.
- luciensis, 103, 154.
- hemicidaroides, Acrosalenia, 111, 112, 113, 157, 164, 174.
- Hemidiadema stramonium, 103, 154.
- hemisphaericus (by error spelt hemisphericus), Holecypus, 148, 491.
- Heterocentrotus, 217, 361.
- mamillatus, 147, 163, 164.
- trigonarius, 147, 163, 166.
- Heterocidaris, 433, 456, 457.
- keokuk, 267, 433, 456, 457.
- laevispina, 433, 456, 457.
- hieroglyphicus, Glypticus, 103, 154.
- Hind, Wheelton, 272.
- Hipponoz, 361.
- hispidum, Echinoma, 34, 57, 185.
- hoffmanni, Hemicidaris, 154.

- Holoetypina, 28, 55, 62, 78, 188, 189, 196, 198, **204**, 208, 209, 217, 218, 223.
 Holoetypus, 150, 170.
 hemisphaericus (by error spelt hemisphericus), 148, 491.
 Holopneustes, 361.
 purpureseens, 159.
Homotoechus, 407.
Homotoechus hartii, 408.
 horridum, Dermatodiadema, 154.
 [Humphreys, George], 27.
 Hupé, M. H. See Dujardin, M. F., and Hupé, M. H.
 Huxley, Thomas, 31.
 Hyatt, Alpheus, 9, 14, 15, 16, 17, 66, 199, 232, 292, 296, 349.
Hyattechinus, 18, 23, 34, 58, 61, 71, 74, 81, 85, 86, 89, 190, 194, **206**, 209, 213, 225, 226, **291**, 299, 394, 395, 400.
 beecheri, 12, 16, 17, 22, 25, 28, 32, 34, 64, 65, 67, 173, 210, 225, 226, 237, 292, 293, **297**.
 pentagonus, 17, 21, 22, 32, 66, 67, 210, 225, 237, 292, 293, **295**, 298.
 rarispinus, 12, 17, 21, 22, 25, 32, 50, 66, 77, 210, 225, 237, 251, 290, **292**, 296, 297, 298, 395, 396.
Hybochinidae, 393.
Hybochinus, 412.
 spectabilis, 76, 421.
Hyboechinus spectabilis, 421.
Hypsiechinus, 65, 210.
 hystrix, Asthenosoma, 156.

 iijimai, Asthenosoma, 109, 110, 156.
 illinoisensis, Archaeocidaris, 258, **266**.
 Perisechodomus, 233, 401, **406**.
illinoisensis, *Tretechinus*, 406.
 imbricatus, Lepidechinus, 52, 237, 394, 395, 397, 398, **399**.
imbricatus, *Lepidocentrus*, 399.
 imperialis, Phyllacanthus, 100, 102, 194.
 indianana, Pseudoboletia, 126, 162.
 indianensis, Melonechinus, 15, 16, 67, 230, 231, 364, **369**, 373, 381, 385, 390.
indianensis, *Melonites*, 369.
 indistinctum, Kamptosoma, 34.
 intermedia, Hemieidaris, 103, 154.
 Maecoya, 60, 89, 227, 303, 308, 312, **314**, 321, 322, 323, 335.
intermedius, *Palacchinus*, 314.
 Palaeochinus, 303, 314.
 Palechinus, 314.
intricatus, *Lepidechinus*, 399.
iowensis, *Lepidechinus*, 337, 395, **397**, 398.
 irregularis, *Lepidechinus*, 237, 395, **396**.
irregularis, *Lepidocentrus*, 434.
 Melonechinus, 375.
 Melonites, 375, 380.
 irregularis, Pholidocidaris, 76, 234, 237, 433, **434**, 440, 441, 442, 457.
irregularis, *Rhocchinus*, 303, 394, 396.

 Jackson, R. T., 10, 14, 18, 19, 50, 64, 68, 71, 76, 107, 171, 175, 199, 210, 232, 243, 289, 293, 295, 321, 323, 341, 354, 358, 380, 391, 393, 394, 434, 438, 439.
 Jackson, R. T., and Jaggar, T. A., Jr., 68, 362, 376, 377, 378, 381, 439.
 Jaekel, Otto, 10, 88, 239, 241, 242.
 Jaggar, T. A., Jr., 9.
 Jaggar, T. A., Jr. See Jackson, R. T., and Jaggar, T. A., Jr.
jeffreysi, Pourtalesia, 52, 72.
josephinae, *Palaeotropus*, 53.
 Julien, Alphonse, 10, 263, 327, 328, 442, 396, 451, 452.

kaiserlingi, *Eocidaris*, 245, 246.
Kamptosoma indistinctum, 34.
kaskaskiensis, *Agelacrinus*, 458.
kaskaskiensis, *Diseocystis*, **458**.
kaskaskiensis, *Echinodiscus*, 458.
 Keeping, Walter, 10, 278, 314, 315, 321, 322, 385, 386, 387, 395, 396, 402, 403, 457.
keepingi, *Melonechinus*, 230, 231, 364, **384**, 386, 391.
 keokuk, Archaeocidaris, 258, 259, **267**, 457.
 keokuk, *Heterocidaris*, 267, 433, 456, 457.
 Keyes, C. R., 10, 172, 266, 268, 273, 335, 363, 379, 380.
keyserlingi, *Cidaris*, 245.
 Eocidaris, 246.
 Eotiaris, 246.
keyserlingi, *Miocidaris*, 190, 212, 238, **245**, 248, 249.
 Kitchin, F. L., 112, 275, 278, 450.
 Klem, Mary J., 10, 67, 235, 267, 268, 270, 271, 311, 353, 355, 366, 368, 377, 380, 392, 394, 434, 438, 451, 458.
klipsteini, *Cidaris*, 245.
 Miocidaris, 245.
 Koehler, René, 120.
koenigi, *Palaeochinus*, 451.
königi, *Palaeochinus*, 451.
koenigii, *Echinus*, 450.
 Palaeochinus, 450.
 Palaeochinus, 451.
 Xystria, 451.
konigii, *Palaeochinus*, 304, 305, **450**, 451.
 Koninek, Laurent de, 280, 303, 312, 317, 318, 326, 330, 333, 409, 410, 411, 412.
konineki, Archaeocidaris, 258, **446**.
konincki, *Eocidaris*, 446.
 Palaeochinus, 305, 451.
 Palechinus, 451.
Koninekoeidaris, **206**, 209, 224, 225, **284**.
 eotteau, 11, 224, 225, 237, 284, **285**, 286.
 silurica, 225, 236, 284, **285**, 287, 289, 414.

laeazei, Lovenechinus, 11, 28, 34, 50, 89, 172, 303, 305, 307, 308, 312, 317, 318, 320, **326**.
laeazei, *Maccoya*, 326.
 Palaeochinus, 304, 326.
 Palechinus, 326.
ladina, Archaeocidaris, 258, **446**.
laevis, Archaeocidaris, 262.
laevis, Lepidesthes, 415, **418**.
lacvispina, *Cidaris*, 255, 256.
laevispina, Eocidaris, 223, 236, **255**.

- laevispina*, *Heterocidarid*, 433, 456, 457.
Laganum, 219.
 diploporum, 218.
 Lambert, Jules, 280.
 Lambert, Jules, and Thiéry, P., 235, 257, 267, 305, 308, 394, 410, 442, 457.
 Lang, Arnold, 51, 179, 186.
langrunensis, *Hemicidarid*, 103, 154.
legraudensis, *Archaeocidarid*, 256, 258, 260.
Lepas diadema, 27.
Lepidechinus, 10, 52, 74, 89, 171, 205, 207, 209, 225, 232, 237, 284, 303, 304, 393, 394, 396, 401.
 colcaui, 285.
 imbricatus, 52, 237, 394, 395, 397, 398, 399.
 intricatus, 399.
 iowensis, 237, 395, 397, 398.
 irregularis, 237, 395, 396.
 rarispinus, 290, 292, 394, 395, 396, 400.
 squamosus, 282.
 tessellatus, 52, 89, 221, 232, 237, 395, 397.
Lepidesthes, 412.
Lepidesthes, 10, 27, 34, 66, 71, 74, 78, 81, 171, 181, 208, 209, 213, 232, 233, 237, 397, 401, 403, 404, 406, 412, 421, 426, 432, 433, 445.
 caledonica, 416, 432.
 carinata, 408, 412, 416, 424.
 colletti, 28, 31, 34, 53, 54, 59, 75, 172, 174, 234, 416, 420, 425, 431, 443.
 coreyi, 25, 32, 415, 423, 424.
 corveyi, 423.
 devonians, 236, 415, 420, 432.
 extremis, 12, 237, 416, 418, 421, 430, 443.
 formosa, 28, 34, 89, 172, 174, 234, 394, 415, 418, 423, 426, 427.
 formosus, 418.
 lacvis, 415, 418.
 spectabilis, 76, 415, 421.
 wortheni, 17, 27, 74, 374, 415, 416, 426, 444.
Lepidesthidae, 54, 174, 207, 209, 232, 236, 238, 393, 401, 407, 410, 424.
Lepidocentridae, 206, 209, 213, 221, 224, 233, 236, 237, 252, 284, 302, 393, 401, 404, 405.
Lepidocentrus, 66, 71, 74, 77, 171, 190, 206, 209, 225, 236, 284, 286, 289, 291, 299.
 desori, 287, 457.
 drydenensis, 236, 287, 288.
 duponti, 287, 457.
 eifelianus, 236, 287, 291.
 gaudryi, 287, 457.
 imbricatus, 399.
 irregularis, 434.
 mülleri, 76, 225, 236, 286, 287, 289, 291.
 münsterianus, 280, 442.
 mulleri, 289.
 rarispinus, 292.
 rhenanus, 236, 287, 288, 298.
 whitfieldi, 32, 237, 287, 290, 294.
Lepidocidaridae, 254.
Lepidocidarid, 29, 74, 77, 177, 206, 209, 223, 224, 236, 282, 491.
Lepidocidarid (*continued*).
 squamosus, 282.
 squamosa, 224, 282.
 squamosus, 282.
Lepidechinus, 291.
 atlanticus, 121.
 gracilis, 291.
linulurus, *Dalmanites*, 286.
liratus, *Melonechinus*, 362, 364, 367, 374, 377.
Lituities, 17.
lividus, *Strongylocentrotus*, 35, 46, 48, 52, 126, 127, 130, 132, 150, 151, 153, 162, 164, 179.
lixula, *Arbacia*, 40, 47, 70, 114, 158, 161, 187, 192, 194, 195.
longispina, *Archaeocidarid*, 237, 258, 261.
longispinus, *Centrostephanus*, 108, 110, 156.
Loriol, Percival de, 35, 49, 50, 115, 119, 120, 166, 176.
Lovén, Sven, 10, 18, 20, 23, 26, 28, 29, 32, 33, 34, 52, 53, 55, 56, 61, 64, 65, 67, 70, 71, 72, 79, 83, 86, 92, 101, 106, 129, 170, 172, 174, 178, 180, 181, 182, 188, 189, 190, 192, 194, 195, 196, 198, 210, 211, 213, 216, 218, 219, 220, 235, 241, 243, 288, 306, 326, 349, 381, 420.
Lovenechinus, 18, 20, 27, 32, 52, 53, 58, 66, 67, 73, 89, 171, 172, 173, 190, 192, 207, 209, 227, 228, 237, 303, 304, 312, 324, 350, 351, 354, 356, 357, 360, 361, 365, 380, 381, 385, 390, 412, 450.
 anglicus, 304, 321, 326, 346.
 lacazei, 11, 28, 34, 50, 89, 172, 303, 305, 307, 308, 312, 317, 318, 320, 326.
 missouriensis, 15, 16, 17, 22, 23, 25, 50, 52, 54, 55, 59, 60, 67, 89, 192, 228, 229, 230, 231, 311, 325, 326, 337, 347, 348, 349, 412.
 mutatus, 326, 335, 348.
 nobilis, 73, 326, 335, 339.
 septies, 23, 50, 59, 67, 68, 73, 228, 304, 307, 326, 335, 348, 351, 439.
loveni, *Palaechinus*, 305, 458.
Lovenia, 204.
 forbesi, 72.
luciensis, *Hemicidarid*, 103, 154.
lucunter, *Echinometra*, 35, 39, 91, 141, 146, 147, 150, 151, 153, 163, 164, 192, 195, 217.
Ludwig, Hubert, 61.
Mac Coya, 311.
 gigas, 321.
Maccoya, 20, 58, 66, 73, 89, 173, 207, 209, 227, 303, 304, 310, 311, 317, 318, 320, 321, 325, 339, 340, 341, 345, 347, 356, 360, 363, 372, 381, 452.
 burlingtonensis, 54, 55, 59, 60, 227, 229, 230, 231, 300, 303, 312, 314, 315.
 ellipticus, 307, 326.
 gigas, 303, 312, 321, 346.
 gracilis, 303, 312, 323.
 intermedia, 60, 89, 227, 303, 308, 312, 314, 321, 322, 323, 335.
 lacazei, 326.
 phillipsiae, 227, 236, 237, 303, 312, 316.
 sphaerica, 25, 32, 227, 303, 312, 317, 326, 330.
maculatus, *Microcyphus*, 38, 42, 117, 132, 159, 164, 166.
 Toxopneustes, 121, 161.

- magellanicus, Echinus, 35, 40, 43, 84, 119, 120, 125, 148, 151, 153, 160, 164.
 Magnosia, 104.
 punctata, 155, 491 (by error printed *Magnosia punctulata*, 105).
 punctulata. (See *Magnosia punctata*.)
 magnus, Perischodonus, 401, **453**.
 mammillatus, Heterocentrotus, 147, 163, 164.
 margaritaceus, Echinus, 119, 160, 164.
 mathaei, Echinometra, 146, 147, 151, 153, 163, 164.
 McIntosh, D. C. See Ritchie, Jaimes, and McIntosh, D. C.
 M'Clelland, John, 28.
 M'Coy, Frederick, 10, 257, 262, 275, 278, 280, 302, 305, 307, 308, 309, 312, 317, 318, 321, 322, 329, 330, 401, 402, 403, 450.
 Meek, F. B., 354, 424, 443.
 Meek, F. B., and Worthen, A. H., 10, 76, 177, 283, 313, 335, 336, 356, 358, 363, 379, 414, 423, 435, 436.
Mekechinus, 53, 59, 74, 181, **208**, 209, 234, 393, 415, **442**, 444.
 elegans, 12, 28, 34, 61, 89, 172, 174, 234, 238, 265, 374, 417, 425, 430, **443**.
meeki, *Pholidocidaris*, 76, 434, 435, 438.
megastyla, *Archaeocidaris*, 237, 258, **273**.
megastylis, *Archaeocidaris*, 273.
megastylus, *Archaeocidaris*, 273.
 Cidarotropus, 273.
meijerei, *Aspidodiadema*, 154.
Melechidae, 302.
Melechinus, 359.
Mellita sexiesperforatus, 18.
 melo, Echinus, 118, 160.
Melonechinidae, 302.
Melonechinus, 17, 18, 19, 20, 23, 27, 29, 32, 34, 52, 53, 58, 62, 66, 70, 72, 73, 82, 83, 85, 86, 89, 110, 148, 171, 172, 173, 181, **207**, 209, 228, 229, 237, 253, 302, 304, 325, 339, 341, 350, 351, **359**, 365, 368, 372, 378, 379, 390, 407, 408, 409, 416, 424, 426, 453.
 anceps, 454.
 crassus, 364, **367**.
 dispar, 364, **365**.
 etheridgei, 385.
 etheridgei, 364, 384, **385**.
 giganteus, 16, 17, 21, 60, 61, 68, 230, 231, 361, 362, 364, 377, **389**.
 indianensis, 15, 16, 67, 230, 231, 364, **369**, 373, 381, 385, 390.
 irregularis, 375.
 keepingi, 230, 231, 364, **384**, 386, 391.
 liratus, 362, 364, 367, **374**, 377.
 multiporus, 9, 10, 16, 17, 18, 25, 50, 54, 55, 59, 60, 61, 67, 68, 70, 81, 148, 172, 226, 228, 229, 230, 231, 336, 355, 360, 361, 362, 363, 364, 367, 372, **375**, 389, 390, 391, 392, 439.
 obovatus, 32, 359, 361, 364, **373**, 417, 444.
 parvus, 364, **365**.
 septenarius, 364, **373**.
 springeri, 58, 59, 230, 231, 362, 364, **366**, 369, 381, 385, 390.
Melonechinus (*continued*).
 stewartii, 364, **371**, 379.
 vanderbilti, 68, 364, **388**.
 youngi, 364, 457.
Melonites, 304, 359, 378, 457.
 crassus, 367.
 danae, 356.
 dispar, 365.
 etheridgei, 385.
 gaudryi, 442.
 giganteus, 389.
 granulatus, 389, 392.
 indianensis, 369.
 irregularis, 375, 380.
 multipora, 371, 375.
 multiporus, 354, 369, 371, 375, 389.
 septenarius, 373.
 stewartii, 371.
 youngi, 364, **457**.
Melonitidae, 226, 302, 393.
 Melonitiden, 450.
Melonopsis, 350.
 [*danae*], 356.
 nobilis, 335.
 Meoma, 78, 219.
 Mespilia globula, 159.
 Metalia, 78, 219, 220.
 pectoralis, 54, 57, 58.
 metularia, Eucidaris, 97, 100.
 Meusehen, [F. C.], 468, 469, 491, (by error printed Muerchen, 28).
 mexicanus, Strongylocentrotus, 128, 162.
 Micraster, 52, 57, 69, 72, 92, 150.
 coranguineum, 54, 148.
 Microcyphus, 187.
 annulatus, 166.
 maculatus, 38, 42, 117, 132, 159, 164, 166.
 microtuberculatus, Echinus, 118, 160, 164, 210.
 miliaris, Echinus, 118, 160.
 Orthopsis, 105, 155.
 Salenocidaris, 34, 56, 112, 157.
 Miller, S. A., 261, 268, 419, 456, 457.
 Miller, S. A., and Gurley, W. F. E., 352, 355.
 Miller, S. A. See Worthen, A. H. and Miller, S. A.
 milleri, Porocidaris, 34, 101.
 minor, Asteroecidaris, 103, 154.
minor, Palaeochinus, 305, **310**.
 minutus, Oligoporus, 351, **450**.
 Miocidaris, 78, 103, 182, **201**, 209, 211, **245**, 248, 249, 444.
 cannoni, 212, 236, 238, 245, **247**, 257.
 cassiana, 245.
 keyserlingi, 190, 212, 238, **245**, 248, 249.
 klipsteini, 245.
 mirabilis, Phymechinus, 105, 155.
 missouriensis, Lovenechinus, 15, 16, 17, 22, 23, 25, 50, 52, 54, 55, 59, 60, 67, 89, 192, 228, 229, 230, 231, 311, 325, 326, **337**, 347, 348, 349, 412.
 missouriensis, Oligoporus, 52, 304, 337, 412.
 molare, Echinostrephus, 32.

- Mollusca, 9, 66, 71.
Mortensen, Theodor, 61, 63, 64, 65, 72, 79, 84, 85, 88, 96, 104, 110, 113, 117, 118, 119, 120, 136, 166, 171, 174, 176, 177, 199, 210, 213, 214, 216, 293, 415.
mucronata, Archaeocidaris, 258, 267, **271**, 272, 274.
mucronatus, Archaeocidaris, 271.
Müller, Johannes, 262, 263, 363.
mülleri, Lepidocentrus, 76, 225, 236, 286, 287, **289**, 291.
muensteriana, Archaeocidaris, 259, **280**, 442.
münsteriana, Archaeocidaris, 280.
 Cidaris, 280.
muensterianus, *Cidaris*, 280.
münsterianus, Archaeocidaris, 280.
 Eocidaris, 280.
 Lepidocentrus, 280, 442.
Muerchen (by error, 28), 468, 469, 491. (See Meuschen [F. C.], 468.)
mulleri, *Lepidocentrus*, 289.
multipora, Melonites, 371, 375.
 Palaechinus, 375.
multiporus, Melonechinus, 9, 10, 16, 17, 18, 25, 50, 54, 55, 59, 60, 61, 67, 68, 70, 81, 148, 172, 226, 228, 229, 230, 231, 336, 355, 360, 361, 362, 363, 364, 367, 372, **375**, 389, 390, 391, 392, 439.
multiporus, Melonites, 354, 369, 371, 375, 389.
munsteri, *Eocidaris*, 280.
munsterianus, *Cidarites*, 280.
 Echinocrinus, 280.
 Eocidaris, 280.
mutatus, Lovenechinus, 326, **335**, 348.
mutatus, *Oligoporus*, 304, 335.
Myriastiches, **458**.
 gigas, **458**.
Nautilus, 220.
nerci, Archaeocidaris, 258, **262**.
nerci, *Cidaris*, 262.
 Cidarites, 262.
 Echinocrinus, 262.
 Palaeocidaris, 262.
nerii, Archaeocidaris, 262.
neumayeri, *Echinus*, 119.
 Sterechinus, 119.
Neumayr, Melchior, 88, 312, 407, 409.
Newberry, J. S., 261, 267, 268.
newberryi, Archaeocidaris, 258, **269**.
nicobaricum, Aspidodiadema, 152, 153, 154.
nigra, Arbaeia, 95, 114, 115, 148, 150, 152, 153, 158, 164, 170, 187, 192, 194, 195.
nobilis, Lovenechinus, 73, 326, **335**, 339.
nobilis, Melonopsis, 335.
 Oligoporus, 304, 335.
normannus, Polycyphus, 104, 155.
norwoodi, Archaeocidaris, 258, **270**.
norwoodi, *Cidarotropus*, 270.
nutrix, Goniocidaris, 99, 100, 101, 102, 170.
oblonga, Echinometra, 146, 163.
obovatus, Melonechinus, 32, 359, 361, 364, **373**, 417, 444.
Oligoporus, 10, 18, 73, 181, **207**, 209, 228, 233, 237, 301, 304, 325, 341, **350**, 357, 360, 361, 365, 366, 369, 380, 381, 390, 409, 410, 412.
 bellulus, 351, 352.
 blairi, 304, **351**, 354, 355.
 coreyi, 304, 351, **353**, 355.
 danae, 54, 228, 229, 230, 231, 304, 335, 350, 351, 353, **356**, 491.
 giganticus, 410.
 halli, 304, 351, **355**.
 minutus, 351, **450**.
 missouriensis, 52, 304, 337, 412.
 mutatus, 304, 335.
 nobilis, 304, 335.
 parvus, 365.
 sorcili, 233, 410.
 sp., 355.
 sulcatus, 304, 351, **354**.
Ophiurans, 16.
optatus, Discoecystis, **458**.
optatus, Echinodiscus, 458.
ornata, Archaeocidaris, 258, 267, 271, **274**.
ornatus, Archaeocidaris, 267, 271, 274.
 Echinocrinus, 267, 271, 274.
Orthopsis, 104.
 miliaris, 105, 155.
Osborn, H. L., 35, 39, 90.
ourayensis, Archaeocidaris, 237, 258, **274**.
ovatus, Ananchytes, 112, 148.
ovum, Amblypneustes, 159.
owstoni, Asthenosoma, 156.
pacificus, Toxobrissus, 148.
pahleni, Bothriocidaris, 34, 69, 77, 87, 88, 167, 210, 239, 240, **242**, 244.
pahleni, Botriocidaris, 242.
 Botryocidaris, 242.
Palaechinid, 64.
Palaechinidae, 88, 302, 363.
Palaechinus, 82, 288, 304, 311, 312, 396, 450.
 agassizi, 305, **457**.
 burlingtonensis, 303, 312.
 carpenteri, 305, **458**.
 danae, 356.
 elegans, 308, 332.
 ellipticus, 305, 307, 326, 329.
 gigas, 304, 321, 332, 346.
 gracilis, 303, 323.
 intermedius, 314.
 koenigi, 451.
 kōnigi, 451.
 koenigii, 450.
 konigii, 304, 305, **450**, 451.
 konincki, 305, 451.
 lacazei, 304, 326.
 loveni, 305, **458**.
 multipora, 375.
 paradoxus, 270.
 phillipsiae, 316.

Palaeochinus (continued).

- quadriseptalis*, 305.
rhenanus, 288.
robineti, 305, **452**.
rutoti, 396.
 sp., 305, 326, **458**.
sphaericus, 303, 312, 317, 318, 326, 328, 330.
sphericus, 317, 326.
verneuilliana, 245.
- Palaeochinidae, 10, 16, 17, 54, 66, 67, 68, 70, 72, 73, 74, 78, 82, 83, 104, 172, **207**, 209, 226, 229, 230, 232, 237, 254, **302**, 305, 362, 363, 378, 384, 393, 400, 405, 407, 410, 412, 413, 420, 451, 454.
- Palaeochinoida*, 234, 448.
- Palaeochinus, 10, 18, 23, 27, 53, 54, 58, 60, 63, 66, 67, 83, 89, 171, 173, 190, **207**, 209, 227, 228, 232, 237, 302, 303, **304**, 305, 310, 311, 312, 313, 317, 320, 325, 340, 341, 356, 360, 363, 372, 381, 385, 394, 395, 396, 400, 452, 453, 454.
- burlingtonensis*, 303, 313.
elegans, 54, 59, 89, 229, 230, 231, 303, 305, **308**, 403, 414, 420.
ellipticus, 31, 303, 305, 306, **307**, 308, 326, 329.
gigas, 303, 304, 321, 346.
gracilis, 303, 323.
intermedius, 303, 314.
königi, 451.
minor, 305, **310**.
phillipsiae, 303, 316.
quadriseptalis, 16, 22, 27, 67, 68, 191, 227, 303, **305**, 307, 308, 309, 313, 349, 439.
regnyi, 305, **451**.
sphaericus, 303, 317, 326, 328.
- Palaeocidaris*, 256, 257.
ellipticus, 307.
exilis, **453**.
nerei, 262.
prisca, 276.
prolei, 262.
rhenanus, 288, 455.
rossica, 263.
- Palaeodiscidae, **205**, 209, 221, **250**.
- Palaeodiscus, 81, 177, 181, 200, 209, 211, 213, **250**, 251, 252, 295.
ferox, 222, 236, **250**.
gothicus, 250, **453**.
- Palaeoechinus dispar*, 365.
paradoxus, 270.
- Palaeospatangus skiptoni, **453**.
- Palacotropus josephinae, 53.
- Paleochinus*, 304, 311.
dispar, 365.
ellipticus, 307, 326.
gigas, 321, 346.
intermedius, 314.
konincki, 451.
lacazei, 326.
phillipsiae, 303, 312, 316.
rutoti, 396.

Palcchinus (continued).

- sp., **452**.
sphaericus, 317, 326.
- Palechthinus dispar*, 365.
- palheni*, *Bothriocidaris*, 242.
- pallidum, *Chaetodiadema*, 108, 110, 156.
- pallidus, *Amblypneustes*, 159.
- panamensis, *Cidaris*, 34.
- panamensis, *Dorocidaris*, 34.
- papillata*, *Cidaris*, 61, 182.
- papillata*, *Dorocidaris*, 96.
- paradoxa, *Archaeocidaris*, 237, 258, **270**.
- paradoxa, *Echinostigma*, 72.
- paradoxa*, (*Pourtalesia*), 72.
- paradoxus*, *Palaeochinus*, 270.
- Palaeoechinus*, 270.
- Parasalenia, 176, 203, 204, 215.
gratiosa, 176.
- parma, *Echinarachnius*, 35, 49, 54, 56, 58, 81, 179, 189, 196, 197.
- parvus, *Melonechinus*, 364, **365**.
- parvus*, *Oligoporus*, 365.
- pattersoni, *Salenia*, 88, 111, 157, 170, 171, 172.
- pectoralis, *Metalia*, 54, 57, 58.
- Pedina, 104.
rotata, 155.
- Pelanechinus*, 61.
corallinus, 444.
- Pelecypoda, 14, 71, 199.
- Pelmatozoa, 77.
- Peltastes, 11, 174, 175, 214.
stellulata, 156.
wrighti, 11, 157, 174, 398.
- peltatus, *Goniopygus*, 103, 154.
- pentagonus**, *Hyattechinus*, 17, 21, 22, 32, 66, 67, 210, 225, 237, 292, 293, **295**, 298.
- Perischocidaris*, 59, 77, 78, 171, **208**, 209, 211, 233, 237, **407**.
hartei, 408.
harteiana, 10, 233, 237, 407, **408**, 424, 491.
- Perischodomus*, 10, 18, 65, 67, 71, 74, 190, **207**, 209, 210, 233, 237, 284, 393, 396, **401**, 404, 405, 407.
biserialis, 64, 70, 76, 233, 237, 309, **401**, 411.
bisserialis, 401.
[colteau], 285.
gracilis, 291.
hartei, 408.
harteiana, 491.
illinoisensis, 233, 401, **406**.
magnus, 401, **453**.
- Perischocchinida*, 253.
- Perischocchinidae*, 253.
- Perischocchinoida*, 29, 30, 79, 181, 182, 183, 186, 188, 192, 194, 196, **205**, 209, 211, 212, 220, 221, 222, **253**, 350, 361, 362, 363, 379, 408, 413, 414, 415, 417, 438, 446.
- perlatus, *Stomechinus*, 155.
- Permocidaris*, 245, 256, 257.
forbesi, 280.
forbesiana, 280.

- Permoeidaris* (continued).
verneuli, 246.
Peronella peronii, 170.
peronii, *Peronella*, 170.
petalifera, *Salenia*, 111, 157.
phaleni, *Bothriocidaris*, 242.
Phillips, John, 262, 278, 279.
phillipsiae, *Maccoya*, 227, 236, 237, 303, 312, 316.
phillipsiae, *Palaechinus*, 316.
Palaechinus, 303, 316.
Palechinus, 303, 312, 316.
Wrightella, 316.
Wrightia, 316.
Pholidechinus, 34, 66, 71, 74, 81, 86, 171, 178, 181, 182, 185, 206, 209, 226, 299.
brauni, 184, 226, 237, 265, 295.
Pholidocidaris, 18, 66, 71, 74, 77, 78, 181, 208, 209, 234, 237, 393, 413, 414, 432, 440, 441, 442, 443, 444.
acuaria, 236, 433, 441.
gaudryi, 11, 237, 280, 433, 442.
irregularis, 76, 234, 237, 433, 434, 440, 441, 442, 457.
meckii, 76, 434, 435, 438.
sp., 440.
tenuis, 237, 433, 440.
Phormosoma, 18, 28, 30, 56, 58, 64, 65, 69, 71, 73, 79, 81, 83, 85, 86, 110, 145, 168, 183, 185, 186, 195, 200, 210, 225, 292.
placenta, 34, 52, 81, 110, 148, 150, 156, 185, 192.
zeylandiae, 34.
Phyllacanthus, 56, 61, 82, 83, 102, 293, 297.
annulifera, 101, 102, 150, 152, 153.
baculosa, 99, 101, 102, 148, 150, 152, 153, 192, 194.
imperialis, 100, 102, 194.
thomasi, 100, 102.
**Phymechinus*, 101, 110.
mirabilis, 105, 155.
Phymosoma, 215.
crenulare, 112, 186.
delanareii, 113, 158.
Phymosomatidae, 113, 158, 186, 203, 209, 214, 215.
pileolus, *Toxopneustes*, 121, 161.
pizzulana, *Archaeocidaris*, 258, 272.
pizzulana, *Cidarotropus*, 272.
placenta, *Arachnoides*, 72.
Phormosoma, 34, 52, 81, 110, 148, 150, 156, 185, 192.
Plesiocidaroida, 205, 209, 220.
Pleurechinus döderleini, 84, 216.
Plexechinus, 71.
cinetus, 70.
Podocidaris, 215.
Polycephalus, 101.
normannus, 104, 155.
Pomel, Auguste, 11, 303, 304, 312, 451.
pomum, *Cystocidaris*, 252.
pomum, *Echinocrinus*, 258, 449, 456.
pomum, *Echinocystis*, 252.
pomum, *Echinocystites*, 34, 172, 222, 236, 252.
Porocidaris, 297.
cobosi, 34, 61, 89, 414.
milleri, 34, 101.
Portlock, J. E., 278, 279.
Pourtalesia, 86, 204, 219.
jeffreysi, 52, 72.
paradoxa, 72.
Pourtalesiidae, 200.
princeps, *Tiarechinus*, 70.
prisca, *Archaeocidaris*, 11, 259, 276.
prisca, *Echinocrinus*, 276.
Palaeocidaris, 276.
priscus, *Archaeocidaris*, 276.
Cidarites, 276.
Echinocrinus, 276.
profundi, *Salenocidaris*, 111, 112, 157.
Prosechinus, 407.
hartianiana, 408.
protei, *Archaeocidaris*, 262, 263.
Cidarites, 262.
Echinocrinus, 262.
Palaeocidaris, 262.
Proterocidaris, 208, 209, 233, 237, 409, 412.
giganteus, 233, 237, 409, 410.
Protocidaris, 432, 442.
acuaria, 441.
Proto Echinus, 451.
Protocchinus, 453.
anceps, 449, 453, 454.
Prouho, Henri, 61.
Pseudoboletia indiana, 126, 162.
pseudodecorata, *Acrosalenia*, 112, 148, 150, 152.
Pseudodiadema, 105, 106.
pseudodiadema, 104, 105, 155.
pseudodiadema, *Pseudodiadema*, 104, 105, 155.
pulchellus, *Gymnechinus*, 93, 94, 120, 123, 133, 152, 160, 164, 165, 166.
pulcherrimus, *Sphaerechinus*, 126, 162.
pulvinata, *Astropyga*, 74, 76, 109, 156.
punctata, *Magnosia*, 155, 491 (by error printed *Magnosia punctulata*, 105).
punctulata, *Arbacia*, 35, 37, 39, 41, 42, 44, 45, 46, 48, 50, 58, 114, 115, 141, 151, 152, 153, 158, 164, 170, 171, 175, 176, 179, 185, 187.
punctulata, *Magnosia*. (See *punctata*, *Magnosia*.)
purpuratus, *Strongylocentrotus*, 32, 140, 144, 151, 153, 162.
purpureseens, *Holopneustes*, 159.
pusillus, *Echinocyaneus*, 70.
pustulata, *Acrosalenia*, 112, 157, 164.
Pygastrides, 208.
Pygmaecidaris, 215.
quadrangularis, *Rhocchinus*, 305.
quadriscialis, *Palaechinus*, 305.
quadriscialis, *Palaechinus*, 16, 22, 27, 67, 68, 191, 227, 303, 305, 307, 308, 309, 313, 349, 439.
quadriscialis, *Rhocchinus*, 303, 305.
Quenstedt, F. A., 288, 306, 308, 378, 455.
radiata, *Astropyga*, 156.
radiatus, *Glyphocyphus*, 117, 159, 216.
Randall, F. A., 299.
rankini, *Archaeocidaris*, 11, 259, 276, 449.

- Ranzani, Camillo, 27, 28.
 rarispinus, Hyattchinus, 12, 17, 21, 22, 25, 32, 50, 66, 77, 210, 225, 237, 251, 290, **292**, 296, 297, 298, 395, 396.
rarispinus, *Lepidechinus*, 290, 292, 394, 395, 396, 400.
Lepidocentrus, 292.
 reevesii, Temnopleurus, 117, 159.
regimontana, *Archaeocidaris*, 277, 279.
regnyi, *Palaeochinus*, 305, **451**.
 rhcnanus, *Lepidocentrus*, 236, 287, **288**, 298.
rhenanus, *Palacchinus*, 288.
Palacocidaris, 288, 455.
Rhoechinidae, 284, 393.
Rhoechinus, 303, 304, 305, 312, 394, 395, 396, 454.
burlingtonensis, 313, 323.
elegans, 303, 308, 314.
gracilis, 323.
irregularis, 303, 394, 396.
quadrangularis, 305.
quadriserialis, 303, 305.
 sp., 303, 305, **454**.
 Ribaucourt, Edouard de, 35, 48, 50.
 Ritchie, James, and McIntosh, D. C., 35, 44.
 robillardi, *Gymnechinus*, 93, 94, 120, 160, 164, 165, 166.
 robineti, *Palaeochinus*, 305, **452**.
 rogersi, *Centrostephanus*, 108, 110, 152, 153, 156.
 rosaccus, Antedon, 52.
 Clypeaster, 73, 185, 196, 197.
 rossica, *Archaeocidaris*, 77, 82, 177, 184, 224, 255, 256, 258, **263**, 456.
rossica, *Cidarotropus*, 263.
Echinocrinus, 263.
Eocidaris, 263.
Palaeocidaris, 263.
 var. *schellwieni*, *Archaeocidaris*, 263, 264.
rossicus, *Archaeocidaris*, 263.
Cidaris, 263.
Cidarites, 263.
Eocidaris, 263.
 rotata, Pedina, 155.
 Rotula, 71.
 dentata, 70.
rutoti, *Palaeochinus*, 396.
Paleochinus, 396.
 Safford, J. M., 372.
 Salenia, 65, 69, 71, 85, 89, 111, 112, 172, 174, 175, 176, 183, 186, 187, 194, 195, 214.
 cincta, 112, 157.
 clarki, 111.
 pattersoni, 88, 111, 157, 170, 171, 172.
 petalifera, 111, 157.
 scutigera, 111, 157.
 Saleniidae, 78, 87, 92, 93, 111, 112, 113, 156, 157, 174, 176, 195, **203**, 209, 214, 216, 220.
Salenocidaris, 174.
 miliaris, 34, 56, 112, 157.
 profundus, 111, 112, 157.
 varispina, 111, 112, 151, 153, 157.
 Salmacis alexandri, 159.
 Salmacis (*continued*).
 bicolor, 159.
 sphacroides, 159.
 Salter, J. W., 251.
 sampsoni, *Discocystis*, **458**.
 sampsoni, *Echinodiscus*, 458.
 Sarasin, Paul and Fritz, 62, 179.
 sceptifera, *Cidaris*, 95.
 (*Schizaster*) *fragilis*, 177.
 Schmidt, Friedrich, 10, 87, 242, 243, 244.
 Schultze, Ludwig, 290.
 Schumacher, C. F., 27.
 scotica, *Archaeocidaris*, 258, **447**.
scrobiculata, *Cidaris*, 255.
Eocidaris, 255.
 scutata, *Habrocidaris*, 172, 175.
 scutigera, *Salenia*, 111, 157.
 selwyni, *Archaeocidaris*, 238, 258, **447**.
 semituberculatus, *Toxopneustes*, 121, 161.
 septenarius, *Melonechinus*, 364, **373**.
septenarius, *Melonites*, 373.
septies, *Lovenechinus*, 23, 50, 59, 67, 68, 73, 228, 304, 307, 326, 335, **348**, 351, 439.
setosum, *Diadema*, **28**, 104.
 setosus, *Centrochinus*, **28**, 76, 104-109, 110, 152, 153, 155, 164, 167, 168, 170, 183, 185, 191, 192, 213.
 sexiesperforatus, *Mellita*, 18.
 Shumard, B. F., and Swallow, G. C., 273, 274.
 shumardana, *Archaeocidaris*, 258, **268**.
 shumardanus, *Archaeocidaris*, 268.
 shumardi, *Archaeocidaris*, 268.
 shumardiana, *Archaeocidaris*, 268.
 shumardina, *Archaeocidaris*, 268.
 sigsbeii, *Conolampas*, 198.
silurica, *Koninckocidaris*, 225, 236, 284, **285**, 287, 289, 414.
 sixi, *Archaeocidaris*, 258, **447**.
 skiptoni, *Palaeospatangus*, **453**.
 Smith, John, 457.
 Solaster, 35.
 Sollas, W. J., 177, 211, 222, 251, 252, 253, 295, 407, 409.
 soreili, *Oligoporus*, 233, 410.
 sp., *Archaeocidaris*, 269, 272, 281, 408, 447, **448**, **449**.
Echinoerinus, **450**.
Palaeochinus, 305, 326, **458**.
Palaeochinus, **452**.
Pholidocidaris, **440**.
Rhoechinus, 303, 305, **454**.
 sp., *Oligoporus*, 355.
 sp. a., *Archaeocidaris*, 272.
 sp. b., *Archaeocidaris*, 237, 259, **281**.
 sp. b. var., *Archaeocidaris*, 281, 282.
 sp. c., *Archaeocidaris*, 281, 282.
 sp. d., *Archaeocidaris*, 281, 282.
 Spatangina, 78, 92, 189, 198, **204**, 209, 219.
 Spatangoids, 18, 26, 29, 33, 45, 56, 57, 58, 60, 62, 64, 65, 69, 71, 72, 78, 79, 85, 86, 87, 92, 167, 170, 190, 200, 210, 217, 218, 241.
 Spatangopsis, **458**.

- Spatangopsis* (*continued*).
costata, 458.
Spatangus, 73.
spatuligera, Arbacia, 95, 115, 116, 158, 164.
spectabilis, *Hyboechinus*, 76, 421.
Hyboechinus, 421.
spectabilis, *Lepidesthes*, 76, 415, 421.
 Spenceer, Herbert, 15.
 Spenceer, W. K., 222, 250, 251, 252.
Sperosoma, 415.
giganteum, 118.
grimaldi, 415.
Sphaerechinus, 187.
granularis, 93, 126, 141, 162, 164, 179.
pulcherrimus, 126, 162.
sphaerica, Maccoya, 25, 32, 227, 303, 312, 317, 326, 330.
sphaericus, *Eriechinus*, 317, 326.
Palaechinus, 303, 312, 317, 318, 326, 328, 330.
Palaeccchinus, 303, 317, 326, 328.
Palechinus, 317, 326.
Typhlechinus, 317, 326.
sphaeroides, *Salmacis*, 159.
sphericus, *Palaechinus*, 317, 326.
spinoclavata, *Archaeocidaris*, 237, 259, 281.
spinoclavatus, *Archaeocidaris*, 281.
spinosa, *Aerosalenia*, 111, 112, 157, 174, 175.
spinosa, *Archaeocidaris*, 449.
spinosa, *Echinoerinus*, 258, 449.
 Springer, Frank, 354, 367.
springeri, **Melonechinus**, 58, 59, 230, 231, 362, 364, 366, 369, 381, 385, 390.
squamosus, *Lepidocidaris*, 282.
squamosa, *Eocidaris*, 282.
squamosa, *Lepidocidaris*, 224, 282.
squamosus, *Eocidaris*, 282.
Lepidocchinus, 282.
Lepidocidaris, 282.
 Steinmann, Gustav, 455.
stellata, Arbacia, 114, 158.
stellifera, *Archaeocidaris*, 261, 262.
stellulata, *Peltastes*, 156.
Sterechinus antarecticus, 120.
diadema, 120.
neumayeri, 119.
 Stewart, Charles, 61, 62.
 Stewart, T. H., 177, 179.
stewartii, *Melonechinus*, 364, 371, 379.
stewartii, *Melonites*, 371.
Stirodonta, 111, 113, 156, 157, 158, 174, 183, 186, 187, 188, 189, 203, 209, 214, 215, 217, 218.
Stomechinus, 104, 106.
bigranularis, 104, 105, 155.
granularis, 155.
perlatus, 155.
Stomopneustes, 35, 183, 186, 214, 361.
variolaris, 49, 113, 114, 158, 164, 186, 214, 215.
Stomopneustidae, 92, 93, 113, 158, 203, 209, 214, 216.
stramonium, *Hemidiadema*, 103, 154.
striatus, *Echinoerinus*, 258, 450.
Strongylocentrotidae, 82, 93, 109, 113, 120, 125, 126, 146, 162, 167, 168, 170, 173, 174, 176, 179, 187, 204, 209, 215, 216, 217.
Strongylocentrotus, 32, 44, 45, 46, 47, 53, 55, 58, 63, 65, 69, 71, 73, 79, 83, 85, 88, 107, 110, 119, 126, 167, 170, 172, 174, 176, 177, 178, 179, 180, 181, 182, 183, 187, 194, 210, 216, 217, 265, 301, 361.
albus, 95, 127, 162, 164, 217.
depressus, 129, 162.
dröbachiensis, 32, 35, 36, 37, 38, 40, 41, 42, 43, 44, 45, 47, 48, 49, 52, 54, 55, 78, 81, 83, 88, 90, 91, 126, 127, 128, 129-143, 151, 152, 153, 162, 164, 165, 166, 167, 168, 169, 170, 171, 172, 173, 176, 177-179, 181, 192, 195.
eurythrogrammus, 35, 44, 141, 144, 162.
fragilis, 128, 151, 153, 162.
franciscanus, 60, 142, 144, 148, 150, 162, 164, 171.
gibbosus, 94, 95, 97, 109, 120, 128, 145, 146, 152, 162, 164, 177, 217.
lividus, 35, 40, 48, 52, 126, 127, 130, 132, 150, 151, 153, 162, 164, 179.
mexicanus, 128, 162.
purpuratus, 32, 140, 144, 151, 153, 162.
tuberculatus, 128, 162, 164.
subdepressus, *Clypeaster*, 196, 197.
subquadratus, *Cassidulus*, 148.
suleatus, *Oligoporus*, 304, 351, 354.
 Swallow, G. G. See Shumard, B. F., and Swallow, G. C.
 Synapta, 52.
Tennopleuridae, 84, 85, 92, 117, 119, 159, 176, 179, 187, 203, 209, 216.
Tennopleurus, 187.
hardwickii, 159.
reevesii, 117, 159.
torematicus, 159.
tennesseae, *Archaeocidaris*, 449.
tennesseae, *Cidarites*, 258, 449.
tenuis, *Pholidocidaris*, 237, 433, 440.
Tessellati, 253, 491. (By error spelt *Tesselati*.)
tessellatus, **Lepidechinus**, 52, 89, 221, 232, 237, 395, 397.
Tetracidaris, 60, 201, 211.
 Thiéry, P. See Lambert, Jules, and Thiéry, P.
thomasi, *Phyllacanthus*, 100, 102.
 Thomson, W. T. C., 10, 253, 297.
thouarsi, *Eucidaris*, 62, 97, 100.
Tiarechinus, 71, 87, 210, 220.
princeps, 70.
Tiaris conoideus suevicus, 455.
 Tiddeman, R. H., 385.
tirolensis, *Archaeocidaris*, 258, 456.
torematicus, *Tennopleurus*, 159.
 Tornquist, Alexander, 10, 264, 276, 291, 309, 327, 328, 394, 440, 441, 450, 454.
Tornquistellus, 291.
gracilis, 237, 291.
 Tower, W. L., 35.
Toxobrissus, 150.
pacificus, 148.

- Toxopneustes*, 38, 46, 79, 85, 121, 176, 187, 216.
 atlanticus, 35, 36, 41, 44, 45, 121, 122, 141, 151, 153, 161, 164, 166, 170.
 maculatus, 121, 161.
 pileolus, 121, 161.
 semituberculatus, 121, 161.
 variegatus, 35, 41, 42, 84, 121, 122, 123, 151, 153, 161, 164, 165, 166, 216.
trauscholdi, *Cidarotropus*, 448.
Trautsehoid, Hermann, 177, 262, 265, 272, 418.
trautsehoidi, *Archaeocidar*, 258, 448.
Trelechinus, 401.
 illinoisensis, 406.
tribuloides, *Eucidaris*, 35, 45, 54, 58, 61, 62, 70, 75, 81, 82, 92, 96, 97, 98, 99, 100, 102, 146, 152, 153, 167, 171, 174, 182, 184, 191, 192, 248, 249, 445.
trigonarius, *Heterocentrotus*, 147, 163, 166.
Trigonocidar, albida, 159.
Trilobita, 71, 286.
triplex, *Archaeocidar*, 237, 258, 274.
Tripneustes, 19, 40, 46, 47, 62, 78, 88, 123, 169, 183, 187, 361.
 depressus, 123, 161.
 esulentus, 35, 44, 46, 48, 91, 93, 123, 124, 125, 141, 151, 153, 161, 164, 167, 168, 169, 185, 187.
 variegatus, 123, 161, 164.
triserata, *Archaeocidar*, 275.
triserialis, *Archaeocidar*, 258, 275.
triserialis, *Echinocrinus*, 275.
triserrata, *Archaeocidar*, 237, 258, 275.
triserratus, *Archaeocidar*, 275.
Troost, Gerard, 380, 392, 449.
trudifer, *Archaeocidar*, 237, 258, 269.
trudifera, *Archaeocidar*, 270.
tubaria, *Gonioecidar*, 100, 101.
tuberculatus, *Strongylocentrotus*, 128, 162, 164.
Typhlechinus, 311, 312, 326.
 sphaericus, 317, 326.
urei, *Archaeocidar*, 277.
urii, *Archaeocidar*, 82, 256, 257, 259, 276.
urii, *Cidar*, 276, 277.
 Echinocrinus, 277.
uwa, *Cystocidar*, 252.
 Echinocystis, 252.
 Echinocystites, 252.
Valentin, Gabriel, 177.
vanbrunti, *Echinometra*, 146, 147, 151, 153, 163.
vanderbilti, *Melonechinus*, 68, 364, 388.
variegatus, *Toxopneustes*, 35, 41, 42, 84, 121, 122, 123, 151, 153, 161, 164, 165, 166, 216.
 Tripneustes, 123, 161, 164.
variolaris, *Stomopneustes*, 49, 113, 114, 158, 164, 186, 214, 215.
varispina, *Salenocidar*, 111, 112, 151, 153, 157.
verneuili, *Permocidar*, 246.
verneuilliana, *Archaeocidar*, 245, 268.
 Cidar, 245.
 Eocidar, 246, 247.
 Palaechinus, 245.
verneuillianus, *Eocidar*, 246.
verneuilli, *Eocidar*, 246.
Verrill, A. E., 40, 79.
verruculatus, *Echinus*, 120.
vetusta, *Archaeocidar*, 277, 279.
 Cidar, 277, 278, 279.
vetustus, *Archaeocidar*, 277.
 Echinocrinus, 277.
viridis, *Echinometra*, 146, 163.
vulgaris, *Diadema*, 27.

Waagen, William, 280.
Walcott, C. D., 260, 269.
wervecki, *Archaeocidar*, 259, 276.
werwekei, *Archaeocidar*, 276.
Westergren, A. M., 198, 217.
Whidborne, G. F., 420, 421, 441, 442.
White, C. A., 10, 271, 274, 425, 426, 427, 428.
Whitfield, R. P., 290, 400.
whitfieldi, *Lepidocentrus*, 32, 237, 287, 290, 294.
wiltoni, *Aerosalenia*, 111, 112, 157, 175, 176.
Wood, Elvira, 380, 392, 449.
Worthen, A. H., 363.
Worthen, A. H., and *Miller*, S. A., 76, 269, 281, 421, 422.
Worthen, A. H. See *Meck*, F. B., and *Worthen*, A. H.
wortheni, *Archaeocidar*, 70, 81, 82, 224, 256, 257, 258, 259, 264, 267.
wortheni, *Cidarotropus*, 259.
wortheni, *Lepidesthes*, 17, 27, 74, 374, 415, 416, 426, 444.
Wright, Joseph, 306.
Wrightella, 303, 311, 312, 317.
 phillipsiae, 316.
wrighti, *Peltastes*, 11, 157, 174, 398.
Wrightia, 303, 311.
 phillipsiae, 316.
Wrightia, 311, 316.

Xenocidar, 236, 245, 454.
 clavigera, 288, 454, 455.
 conifera, 455.
 cylindrica, 454, 455, 456.
Xystria, 304, 451.
 koenigii, 451.

Young, John, 278, 280, 457.
youngi, *Melonechinus*, 364, 457.
youngi, *Melonites*, 364, 457.

zeylandiae, *Phormosoma*, 34.
Zittel, K. A. von, 10, 250, 251, 302, 458.

ERRATA AND ADDENDA.

- Page 28, line 18, *add* (See pp. 362, 378, 414, 415.).
- Page 28, line 31, *for* Muerehen (1774) *read* Meuschen (1787).
- Page 54, line 28, *for* *Oligoporus danae* Meek and Worthen *read* *Oligoporus danae* (Meek and Worthen).
- Page 105, line 8, *for* *Magnosia punctulata* (Lamarek) *read* *Magnosia punctata* (Quenstedt).
- Page 148, line 34, *for* *Holectypus hemisphericus* *read* *Holectypus hemisphaericus*.
- Page 188, line 5, *for* distinct continuous base *read* discontinuous base.
- Page 208, line 4, *for* and alone on other *read* and usually alone on other.
- Page 208, line 6, *for* Eleven *read* Twelve.
- Page 230, line 33, *for* *Oligoporus danae* Meek and Worthen *read* *Oligoporus danae* (Meek and Worthen).
- Page 232, line 16, *for* twelve *read* thirteen.
- Page 233, line 27, *for* eleven *read* twelve.
- Page 250, after line 26, *add a line reading*: *Echinocystites* (pars) Duncan, 1889a, p. 20.
- Page 251, line 28, *for* sea-urchin, superposed on those of a starfish *read* starfish, superposed on those of a sea-urchin.
- Page 252, line 19, *for* Duncan, 1889a, p. 20, *read* (pars) Duncan, 1889a, p. 20.
- Page 253, line 21, *for* *Tesselati* *read* *Tessellati*.
- Page 272, line 3, *for* 1880, p. 130, *read* 1880a, p. 130.
- Page 272, line 18, *for* Plate 2, fig. u *read* Plate 2, fig. n.
- Page 272, line 19, *for* Plate 25, figs. 1, 1a, *read* Plate 35, figs. 1, 1a.
- Page 282, line 7, *for* Plate 23, fig. 16 *read* Plate 33, fig. 16.
- Page 282, line 13, *for* *Lepidocidaris* Meek and Worthen, 1873, p. 482; *read* *Lepidocidaris* Meek and Worthen, 1869, p. 81; 1873, p. 482.
- Page 287, line 30, *for* Eight columns *read* Apparently nine columns.
- Page 321, line 26, *for* Lambert and Thiéry, 1900, *read* Lambert and Thiéry, 1910.
- Page 356, line 7, *for* *Oligoporus danae* *read* **Oligoporus danae*.
- Page 428, line 9, *for* Plate 78, *read* Plate 71.
- Description of Plate 7, fig. 2, line 6, *for* oculars I and II *read* oculars I and III.
- Description of Plate 67, line 1, *for* *Perischodomus harteiana* *read* *Perischocidaris harteiana*.

DESCRIPTION OF PLATES.

In the plates, the numbers designating figures are in heavy-faced italics, and in all cases they occur below the figures, usually on the left lower side. In order to see the full detail of the heliotype photographic plates, also Plate 57, they should be examined with a reading glass. In most cases only a single page reference is given, which indicates the page on which the species is described. It is inexpedient usually to give references to the morphological or other parts of this memoir where the figures are discussed.

When the correct axes of a specimen are known, these are indicated by the Lovén method of enumeration, the ambulacra being numbered I, II, III, IV, and V, and the interambulacra 1, 2, 3, 4, and 5, the numbers revolving from left to right, or clockwise; when the specimen is viewed from below, Plate 2, fig. 1; when viewed from above, the numbers revolve counter-clockwise, Plate 2, fig. 3.

When the correct axes of a specimen are not known, as in most Palaeozoic Echini, the areas are lettered arbitrarily A, B, C, D, E, F, G, H, I, and J, the ambulacra being lettered B, D, F, H, and J. The lettering revolves from left to right when the specimen is viewed from above, and in external view, Plate 11, fig. 2; when viewed from below, the numbers revolve counter-clockwise, Plate 11, fig. 1 (p. 20).

It is important to bear in mind that when a specimen is viewed from the interior (an external mold is necessarily in internal view), the orientation and the lettering of ambulacral and interambulacral columns of plates are reversed from that seen from the exterior (p. 20), Plate 23, figs. 1 and 3 (compare Plate 55, figs. 1 and 2).

In the text as a whole, the lettering is as follows: *a, b*, the left and right columns of ambulacral plates in an area, Plate 31, fig. 1; or *a, a'*; *b', b*, the two columns of demi-plates, *a, b*, and the two columns of occluded plates, *a', b'*, when there are four or more columns of ambulacral plates in an area, Plate 42, fig. 2; Plate 56, fig. 4.

The interambulacral columns in an area are numbered from 1 upward as they appear passing aborally in a given area, Plate 26; Plate 45, fig. 1. H, the heptagonal plate, associated with the initial pentagonal plate of a new column as introduced, is seen in many Palaeozoic Echini, Plate 45, fig. 1; *g*, genital plate; *oc.*, ocular plate; and *sr.*, suranal plate, Plate 4, figs. 1, 2, and 7. The letter X has no definite meaning, but is used to call attention to specific parts, Plate 25, figs. 1 and 2.

Lettering of the parts of the Aristotle's lantern with the associated muscles is as follows: *b*, brace; *c*, compass; *cap.*, dental capsules; *con.*, condyles of brace; *cr.*, crests of the epiphyses, when such are developed; *e. b.*, external brace muscles; *ep.*, epiphyses; *fo. e.*, and *fo. i.*, external and internal foramina in the brace for articulation with the tubercles of the epiphyses; *gl.*, glenoid cavity of an epiphysis, which receives the condyle of the brace; *i*, intercompass muscles; *i. b.*, internal brace muscles; *ip.*, interpyramidal muscles; *l. p.*, left half of a pyramid; *pr.*, protractor muscles of the lantern; *p. s.*, pyramidal suture that divides the left and right half of a single pyramid; *r*, radial compass muscles; *re.*, retractor muscles of the lantern; *r. p.*, right half of a pyramid; *s*, suture, applied to different parts; *s. d.*, dental slide that supports the tooth; *st.*, styloid processes which are the dorsal extension of the dental slides in certain Echini; *t*, tooth; *tu. e.*, and *tu. i.*, external and internal tubercles of the epiphyses which interlock with corresponding foramina of the braces, Plate 2, figs. 7-17, and 19-21; Plate 5, figs. 1-12.

PLATE 1.

Bothriocidaris archaica sp. nov.

Page 239.

- Fig. 1. Lyckholm Schicht, Ordovician, Hohenholm, Island of Dago, Russia. Height 12 mm., diam. 11.2 mm. Museum für Naturkunde, Berlin, holotype. $\times 3.8$. Two columns of high hexagonal plates in each ambulacral area, pores superposed in a central peripodium. An ambulacral plate drawn in section under ambulacrum IV shows the surface outline and depth of the peripodial pit, also in dotted lines the supposed thickness of the plate and position of ambulacral pores. One column of hexagonal plates in each interambulacral area. The initial plate of each interambulacrum rests on the two plates of the second row of the peristome. (By an error in making my drawing in Berlin, the initial plate of interambulacrum 1 rests on the third instead of the second plate of ambulacrum 1b.) The youngest interambulacral plates dorsally have no tubercles, other interambulacral plates have one to three tubercles each (excepting the second plate in area 2 where it was probably worn off); the greatest number of tubercles is near the mid-zone. In one ambulacral plate tubercles were drawn in from an adjacent plate, otherwise the tubercles of all plates are as observed. There is no resorption of the base of the corona. There are two rows of ambulacral plates on the peristome and of these, the primordial ambulacral plates Ia, IIa, IIIb, IVa, Vb are larger, thus orienting the specimen by Lovén's law. (See text-figs. 2, p. 54; 22, p. 70; 40, p. 80.)
- Fig. 2. Same specimen. $\times 5.1$. Dorsal view. Oculars large, forming a continuous ring adorally, covering the ambulacra and interambulacra completely; genitals small, in the dorsal angles of the oculars (pp. 42, 87). There are about nine periproctal plates. (See text-fig. 162, p. 149.)

Bothriocidaris pahleni Schmidt.

Page 242.

- Fig. 3. Jeweschen Schicht, Ordovician, near Nommis, Esthland, Russia. Height 16 mm., diam. 15.5 mm. Esthlandischen Provinzial Museum, Reval (after Schmidt, 1874, Plate 4, fig. 1a). Holotype, $\times$ about 1.6. Spines and tubercles on ambulacral, but wanting on interambulacral plates. (Compare photograph, Plate 8, fig. 1.)
- Fig. 4. Same specimen (after Schmidt, Plate 4, fig. 1e). $\times$ about 4. Ambulacral pores superposed in a central peripodium, tubercles perforate, on ambulacral plates only.
- Fig. 5. Same specimen (after Schmidt, 1874, Plate 4, fig. 1d) much enlarged. Two primordial ambulacral plates with a (tooth?).
- Fig. 6. Same specimen (after Schmidt, 1874, Plate 4, fig. 1b) enlarged. Dorsal view. Genitals 1 and 4 are dorsal to the oculars, but genitals 2 and 3 separate the oculars and reach the interambulacra (p. 87).

Bothriocidaris globulus Eichwald.

Page 243.

- Fig. 7. Lyckholm Schicht, Ordovician, Hohenholm, Island of Dago, Russia. Height 18 mm., diam., 18.5 mm. (after Schmidt, 1874, Plate 4, fig. 2a). $\times$ about 1.6. Perforate tubercles on both ambulacral and interambulacral plates.
- Fig. 8. Same specimen (after Schmidt, 1874, Plate 4, fig. 2d). $\times$ about 4. Ambulacral plate with pores superposed and perforate tubercles which also occur on interambulacral plates.
- Fig. 9. Same specimen (after Schmidt, 1874, Plate 4, fig. 2b), enlarged. Dorsal view. Genitals all separate the oculars and reach the interambulacral areas (p. 87).

Figs. 1, 2 redrawn by J. Henry Blake from my drawings; Figs. 3-9 copied by W. M. Barrows. The lettering and orientation of all figures are mine.

PLATE 2.

Goniocidaris canaliculata A. Agassiz.

- Figs. 1-3. Falkland Islands. Very young, diam. 1.45 mm. (after Lovén, 1892, Plate 2, figs. 7-9). $\times$ about 26.
- Fig. 1. Ventral view, primordial ambulacral plates only on the peristome, primordial interambulacral plates in basicoronal row, succeeded in the next row by two plates in each area. (Compare text-figs. 23, p. 70; 45, p. 80.) Page 65.
- Fig. 2. Same specimen, side view. Ambulacral plates high hexagonal, pores superposed in each plate. (Compare text-fig. 3, p. 54.) Page 58.
- Fig. 3. Same specimen, dorsal view. Oculars exsert, no genital, but one large madreporic pore. One plate fills the periproct (possibly this single plate is an error, p. 174). (Compare adults, text-figs. 73, 74, p. 99.) Pages 101, 172.
- Fig. 4. Southern part of South America. Diam. 23 mm. R. T. J. Coll., 745. $\times$ 11. Ambulacral plates at mid-zone low, wide; in young plates beneath the ocular, the height equals the width, as at mid-zone in a young individual, fig. 2. Same specimen as text-fig. 74, p. 99. Page 58.

Eucidaris tribuloides (Lamarck).

- Fig. 5. Florida. Diam. 5 mm. R. T. J. Coll., 645. $\times$ 17. Young ambulacral plates in the placogenous zone are high hexagonal. Page 58.
- Fig. 6. Florida. Diam. 5 mm. R. T. J. Coll., 644. $\times$ 21. On the peristome are four or five high, hexagonal ambulacral plates in each column. In the primordial ambulacral row the Ia, IIa, IIIb, IVa, Vb are larger than the Ib, IIb, IIIa, IVb, Va. Two plates in each interradiar area of peristome. (Compare adult, text-fig. 46, p. 80.) Page 82.
- Figs. 7-16. Nassau, Bahamas. R. T. J. Coll., 694. Study of the Aristotle's lantern. Page 182.
- Fig. 7. Side view of pyramid. $\times$ 2.6. The pyramid has ridges for attachment of interpyramidal muscle; epiphysis has a glenoid cavity, *gl.*, and external and internal tubercles, *tu. e.*, *tu. i.*, for interlocking with brace; tooth grooved.
- Fig. 8. Pyramid, face view. $\times$ 2.6. Foramen magnum very shallow; the tooth, epiphyses, braces, and compasses are in place (compare text-fig. 210, p. 184.)
- Fig. 9. Lantern, top view. $\times$ 2.6. In area I all parts are in place; in V the compass is removed; in IV the compass and brace are removed and in area II the epiphyses also are removed to show the smooth upper face of the pyramids. (Compare text-fig. 218, p. 191.)
- Fig. 10. Half-pyramid, inner view. $\times$ 2.6. The pyramidal suture extends nearly to the top, the dental slide reaches only part way to base of foramen magnum as in the *Perischoechinoida*.
- Fig. 11. Pyramid. $\times$ 2.6. Face view, with epiphyses removed.
- Fig. 12. Compass. $\times$ 5.3. Top and side views, separated on the line of the suture.
- Fig. 13. Brace. $\times$ 5.1. Top view.
- Fig. 14. Left epiphyses of area 2, fig. 9. $\times$ 5.4. Top view, to show glenoid cavity, *gl.*, and external and internal tubercles, *tu. e.*, *tu. i.*, for interlocking with the brace.
- Fig. 15. Brace. $\times$ 5.1. Lower view, showing condyles, *con.*, and external and internal foramina, *fo. e.*, *fo. i.*, which interlock with the glenoid cavity and tubercles of the epiphyses.
- Fig. 16. Right epiphysis of area 1, fig. 9. $\times$ 5.2. Lower view. X in both figures shows the face of sutural contact.

Goniocidaris canaliculata A. Agassiz.

- Fig. 17. Falkland Islands. Very young (after Lovén, 1892, Plate 3, fig. 23). Much enlarged. Lantern inclined, foramen magnum deep, interpyramidal muscles long, as in the *Perischoechinoida*. (See text-fig. 209, p. 184.) Page 181.

Phyllacanthus thomasi A. Agassiz and Clark.

- Fig. 18. Hawaiian Islands. Diam. 65 mm. Adapted from A. Agassiz and Clark, 1907, Plate 27. $\times$ 1.7. More than one column of non-ambulacral plates in each interradiar area of the peristome. Page 82.

Phormosoma placenta Wyville Thomson.

- Figs. 19-21. Lat. 40° 53' 30" N. Lat., 66° 24' 00" W. Long. Albatross Station 2530, 956 fathoms. R. T. J. Coll., 778. Study of lantern. Page 185.
- Fig. 19. Face view. $\times$ 3.2. Pyramids wide-angled, with deep rounded foramen magnum, long interpyramidal muscles, compasses very long. Teeth are grooved and styloid processes extend above the base of foramen magnum as they do in other *Centreechinoida* and as they do not in the *Cidaroida* and *Perischoechinoida*.
- Fig. 20. Dorsal view. $\times$ 3.4. Lantern inclined, teeth grooved; in area I the tooth is removed to show dental slides; in area V all parts are in place; in area I the compass is removed; in area IV the compass and brace are removed to show the epiphyses; and in area II the epiphyses also are removed to show the top of half-pyramids with the characteristic pits. (Compare Plate 27, figs. 4-6.)
- Fig. 21. Pyramid, side view. $\times$ 3.5. Showing the tooth, ridges for attachment of interpyramidal muscle, and epiphysis with glenoid cavity.

PLATE 3.

Eucidaris tribuloides (Lamarck).

- Fig. 1. Nassau, Bahamas. Diam. 48 mm. R. T. J. Coll., 741. $\times 7$. Young plate from placogenous zone with developing spine. In lower figure the plate is seen in side view and the spine is removed showing a low imperforate tubercle. The spine is low, concave, saucer-shaped, as seen from the side and partially from lower view; the upper figure is the same plate in face view with spine removed. Page 77.
- Fig. 2. Same specimen. $\times 7$. The same plate in side view with the spine in place. Page 77.

Phyllacanthus baculosa (Lamarck).

- Fig. 3. Mauritius. Diam. 44 mm. R. T. J. Coll., 752. $\times 2$. Oculars V, I, IV insert, an arrested variant. (Compare text-fig. 169, p. 149.) Page 102.
- Fig. 4. Mauritius. Diam. 41 mm. R. T. J. Coll., 753. $\times 2$. Oculars V, I, IV, II insert, III exsert, an arrested variant. Page 102.

Echinus microtuberculatus Blainville.

- Fig. 5. $\times$ about 160 (after Bury, 1895, Plate 7, fig. 34). *oc.*, large oculars each with a four-pronged spine, and huge tentacle, *ten.*; *g*, small genitals; *a, b*, two ambulacral plates each with a six-pronged spine below the ocular; *i*, primordial interambulacral plates each with a six-pronged spine. Pages 65, 87.

Hypsiechinus coronatus Mortensen.

- Fig. 6. Very young (after Mortensen, 1903, Plate 7, fig. 6). Highly magnified. *Oc.*, ocular plates; *a, b*, young ambulacral plates of the corona; *i*, primordial interambulacral plates; *P. A.*, primordial ambulacral plates; *t*, teeth. Page 65.

Schematic young echinoid.

- Fig. 7. Specimen in the protechinus stage. *g*, small genitals; *oc.*, large oculars; *a, b*, young ambulacral plates of the corona; *i*, young primordial interambulacral plates; *P. A.*, primordial ambulacral plates; *t*, teeth. Pages 53, 90.

Phormosoma placenta Wyville Thomson.

- Fig. 8. Young specimen. Diam. 3 mm. (after Mortensen, 1907, p. 24). Highly magnified. The genitals meet in a ring, and as a consequence, the oculars must be exsert. (Compare adult, text-fig. 170, p. 149.) Page 110.
- Fig. 9. Young specimen. Diam. 3 mm. (adapted from Mortensen, 1904, p. 54). Highly magnified. Only one row of primordial ambulacral plates on the peristome; the primordial interambulacral plates are in the basicoronal row. (Compare adult, text-fig. 43, p. 80.) Page 79.
- Fig. 10. Off Nevis, West Indies, 375 fathoms. Diam. 7 mm. (after A. Agassiz, 1904, Plate 43, fig. 1). Two rows of ambulacral plates on the peristome. (Compare *Bothriocidaris*, Plate 1, fig. 1; also text-figs. 41, 43, p. 80.) Page 79.

Strongylocentrotus dröbachiensis (O. F. Müller).

- Fig. 11. Very young specimen. Diam. 1.2 mm. (after Lovén, 1892, Plate 4, fig. 25). $\times$ about 50. Lantern inclined, interpyramidal muscles long, ten primordial ambulacral plates only on the peristome, primordial interambulacral plates in basicoronal row, ambulacral plates of corona high, simple. (Compare text-figs. 49, 50, p. 80.) Page 65.

Phyllacanthus baculosa (Lamarck).

- Fig. 12. Mauritius. Diam. 45 mm. R. T. J. Coll., 901. Ambulacrum II, showing spinules on the interior of ambulacral plates; *c*, from the ambitus, $\times 5.5$, a single spinule over each inner pore; *d*, enlargement of same, $\times 10.3$; *b*, from the base of the corona, $\times 5.5$; another set of blunter spinules appears between the pores and the middle of the area. (Compare Plate 24, fig. 6.) Ventrally, these inner spinules are fused into a continuous ridge (compare text-fig. 224, p. 193). *a*, enlargement of two plates, $\times 10.3$, showing the two sets of spinules. Page 61.

Eucidaris tribuloides (Lamarck).

- Fig. 13. Jamaica. Diam. 43 mm. R. T. J. Coll. Ambulacrum II, showing spinules on the interior of ambulacral plates. $\times 5.3$, and one plate, $\times 10.6$. There are three spinules over the inner pore of each plate. Page 61.

Echinus magellanicus Philippi.

- Fig. 14. Patagonia. Diam. 3 mm. R. T. J. Coll., 894. $\times 19$. Oculars all exsert, no genital pores exist, and only one madreporic pore; the suranal plate fills the periproct. (Compare adult, text-fig. 165, p. 149.) Pages 119, 176.

Collyrites acuta Desor.

- Fig. 15. After Lovén, 1874, Plate 6, fig. 55. In the basicoronal row there are ten primordial ambulacral plates: the *Ia*, *IIa*, *IIIb*, *IVa*, *Vb* are larger each with two pairs of pores, the *Ib*, *IIb*, *IIIa*, *IVb*, *Va* are smaller each with one pair of pores also five primordial interambulacral plates are in the basicoronal row, succeeded in the second row by two plates in each area. Page 56.

PLATE 4.

***Salenia pattersoni* A. Agassiz.**

Figs. 1-5. Off Havana, Cuba, 300 fathoms. Diam. 12 mm. R. T. J. Coll., 669. All drawn from a single specimen.

- Fig. 1. Apical disc seen from the exterior. $\times 6$. Ocular I is insert, all others exsert; ocular and genital pores invisible; few madreporic pores in genital 2; suranal plate is opposite genital 3. Pages 112, 172.
- Fig. 2. Apical disc seen from the interior. $\times 6$. Pores are visible in all ocular and genital plates; only one madreporic opening in genital 2, though there are several pores on the exterior of the same plate, fig. 1. Page 172.
- Fig. 3. Segment of lantern, showing a keeled tooth, foramen magnum deep and open above, narrow epiphyses, brace and compass. $\times 12$. (Compare text-fig. 212, p. 184.) Page 186.
- Fig. 4. The lantern with muscels and perignathic girdle seen from above. $\times 12$. In area IV all parts of the lantern are in place; in V the compass is removed; in I the brace is removed and also the epiphysis of one side, showing therefore in this area on one side an epiphysis, and on the other side the top of the pyramid with its pits. Protractor, *pr.*, and radial compass muscels, *r.*, are inserted on low apophyses; retractors are inserted on styloid auricles. (Compare fig. 5.) Pages 186, 195.
- Fig. 5. To show the perignathic girdle and attachment of lantern muscels to the same. $\times 12$. Protractor and radial compass muscels are inserted on the low apophyses, *ap.*, retractors on the styloid auricles, *au.* Page 195.

***Salenocidaris varispina* A. Agassiz.**

- Fig. 6. Lesser Antilles, 687 fathoms. Diam. 7 mm. R. T. J. Coll., 668. $\times 12$. Ocular I insert, others all exsert. Ocular and genital pores visible; suranal plate opposite genital 3. Pages 112, 174.

***Peltastes wrighti* Desor.**

- Fig. 7. Greensand, Cretaceous, Farringdon, England. Diam. 12.5 mm. R. T. J. Coll., 674. $\times 4$. All oculars exsert; the suranal plate is opposite ocular III. Pages 111, 174.

***Stomopneustes variolaris* (Lamarek).**

- Fig. 8. Ceylon. R. T. J. Coll., 862. $\times 3$. Segment of the lantern; tooth keeled, foramen magnum deep, epiphyses narrow, not meeting in suture; dorsally the half-pyramids extend over the foramen and produce spurs which support the tooth. Page 186.
- Fig. 9. Same specimen. $\times 3$. Dorsal portion of a half-pyramid to show spur of the same that supports the tooth; epiphysis removed. Page 186.
- Fig. 10. Another specimen, same locality. R. T. J. Coll., 868. $\times 4$. Dorsal view of a pyramid, on one side with epiphysis in place, on the other side the epiphysis is removed to show pits in the pyramid, which dorsally by its spurs gives support to the tooth. Page 186.

***Arbacia punctulata* (Lamarek).**

- Fig. 11. Woods Hole, Massachusetts. Diam. 33 mm. R. T. J. Coll., 685. $\times 3$. Interambulacrum 4 has only one column of plates dorsally, genital 4 is absent, oculars IV and V are in contact and cover entirely areas IV, 4, and V. (Compare *Bothriocidaris*, Plate 1, fig. 2; *Tripneustes*, Plate 6, fig. 4.) Pages 45, 88.
- Fig. 12. Florida. R. T. J. Coll., 889. $\times 3$. Genital 4 is wanting, therefore oculars IV, V are in contact and cover ambulacra IV, V, and interambulacrum 4 completely. There are two columns of plates in interambulacrum 4 as usual. (Compare fig. 11 and text-fig. 185, p. 167.) Page 46.

PLATE 5.

Strongylocentrotus dröbachiensis (O. F. Müller).

Figs. 1-12. Mt. Desert, Maine. Studies of the lantern and muscles of the same.

Page 178.

- Fig. 1. Lantern with muscles and perignathic girdle. $\times 4$. Dental capsules, *cap.*, very large; intercompass muscles, *i*, pass beneath the dental capsules; protractor, *pr.*, and radial compass muscles, *r*, are inserted on low apophyses; retractor muscles, *re.*, are inserted on auricles. (Compare text-fig. 229, p. 193.)
- Fig. 2. The lantern, facing pyramid 5, showing interpyramidal muscles, styloid processes of the dental slides, epiphyses, crests, and compasses. $\times 4$. (Compare text-fig. 213, p. 184.)
- Fig. 3. Pyramid of interradius 4 in side view, with corrugations for the attachment of interpyramidal muscles, epiphysis with its glenoid cavity, crest, external and internal tubercles. $\times 4$.
- Fig. 4. A pyramid, showing the origin of the protractor and retractor muscles on the pyramid and epiphysis, left epiphysis removed. The pyramidal suture, *p. s.*; styloid processes, *st.* of the dental slides are visible above the base of the deep foramen. $\times 4$.
- Fig. 5. Pyramid of interradius 4 seen from the center, showing dental slides, corrugations for muscle attachment, and the epiphyses with their glenoid cavities, external and internal tubercles and crests. $\times 4$.
- Fig. 6. Left half-pyramid, the right half being removed, showing tooth and dental capsule in place; also, epiphysis, *ep.*; brace, *b*; and intercompass muscle, *i*; the pyramidal sutural face, *p. s.*, is shaded. $\times 4$.
- Fig. 7. Upper part of pyramid, with dental capsule in place; styloid processes are prominent. $\times 4$.
- Fig. 8. Tooth flattened out. $\times 4$. At the basal growing portion, which lies in the dental capsule, the tooth is grooved, as is the whole tooth in the Cidaridae and other primitive types. Lower down a keel develops, as shown by sections at the points indicated.
- Fig. 9. Top of lantern to show the structure. $\times 4$. At areas 2, 3, a whole tooth is in place; at 1, the pulpy part of the tooth is removed; at 4 and 5 the tooth is removed. At area III the compass, brace, and epiphyses are in place; at V, the compass is removed; at IV the brace also is removed to show the epiphyses; and at I the epiphysis of one side is removed to show the pits in the top of the pyramid.
- Fig. 10. A pyramid of interradius 5 seen from above. $\times 4$. The epiphyses are removed to show the top of the pyramid with its characteristic pits.
- Fig. 11. A brace, seen from below. $\times 4$.
- Fig. 12. Epiphyses with brace in place to show internal and external brace muscles, *e. b.*, *i. b.* $\times 5$.
- Fig. 13. Massachusetts Bay. Diam. 52 mm. R. T. J. Coll., 657. $\times 3$. Madreporic pores are in genitals 2 and 3; oculars I, V insert. Page 172.
- Fig. 14. York, Maine. Diam. 46 mm. R. T. J. Coll., 779. $\times 3$. Madreporic pores are in genitals 1, 2, 3, and oculars II and III. Page 173.
- Fig. 15. York Harbor, Maine. Diam. 47 mm. $\times 3.6$. Oculars I, V insert; an interspace exists between genital 5 and ocular I where the periproct reaches interambulacrum 5 as in some Echinothuriidae, a very rare variant. (Compare text-fig. 170, p. 149.) Pages 63, 177.
- Fig. 16. Calderwood Island, Fox Island Thoroughfare, Maine. Diam. 36 mm. R. T. J. Coll., 822. $\times 3.7$. Partially tetramerous; interambulacrum 1 is wanting, so that ambulaera I, II are in contact throughout. There are five oculars, V only insert, and five genitals, but genital 1 is imperforate and lies dorsal to oculars I, II, a very rare variation. (Compare Plate 1, fig. 2.) Pages 42, 167.

Lettering: *b*, brace; *c*, compass; *cr.*, crests of the epiphyses; *e. b.*, and *i. b.*, external and internal brace muscles, extending from the braces to the epiphyses; *ep.*, epiphyses; *gl.*, glenoid cavity; *i*, intercompass muscles; *ip.*, interpyramidal muscles; *l. p.*, left half-pyramid; *p*, pyramid; *pr.*, protractor muscles; *p. s.*, pyramidal suture; *r*, radial compass muscles; *re.*, retractor muscles; *r. p.*, right half-pyramid; *st.*, styloid process of the dental slide; *t*, tooth; *tu. e.* and *tu. i.*, external and internal tubercles by which the epiphyses interlock with the brace.

PLATE 6.

Arbacia punctulata (Lamarck).

- Fig. 1. Woods Hole, Massachusetts. Diam. 30 mm. R. T. J. Coll., 660. $\times 4$. Almost completely tetramerous. There are four teeth, ambulacra, interambulacra, and oculars, but five genitals. The absent parts are: ocular and ambulaerum II, the right half of interambulacrum 1 and the left half of interambulacrum 2. From this structural deficiency the right half of interambulacrum 2, which is related to ocular III, and the left half of interambulacrum 1, which is related to ocular I, come together and are in contact throughout their length. Same specimen as photograph, Plate 8, fig. 2. Page 39.

Tripneustes esculentus (Leske).

- Fig. 2. Pernambuco, Brazil. Diam. 110 mm. R. T. J. Coll., 739. $\times 1.9$. Completely hexamerous; six teeth, ambulacra, interambulacra, oculars, and genitals, but genitals 3 and 6 are fused. The added parts lie between oculars III and IV. (Compare Plate 7, fig. 7.) Page 46.
- Fig. 3. The same specimen from the mid-zone showing an ambulacral area of the usual width and an interambulacrum narrower than is normal. $\times$ about 0.9. Pages 46, 78.
- Fig. 4. Jamaica. Diam. 75 mm. R. T. J. Coll., 806. $\times 2.8$. Partially hexamerous. Ocular and ambulaerum VI lie between ambulaerum II and interambulacrum 2. Interambulacrum 6 consists of a single column of plates that abuts against oculars II and VI (compare *Bothriocidaridaris* Plate 1, fig. 2). Oculars I, V, IV are insert and genital 3 is split by a horizontal suture (compare text-fig. 190, p. 169). Page 48.

Strongylocentrotus lividus (Lamarck).

- Fig. 5. Naples Station. Diam. 61 mm. R. T. J. Coll., 696. $\times 2.8$. Highly distorted. The madreporite is widely separated from oculars II and III, against which the two columns of interambulacrum 2 abut as usual; genital 5 is similarly separated from oculars V and I, the periproet reaches the interambulacral areas at several points. Pages 52, 63.

Strongylocentrotus dröbachiensis (O. F. Müller).

- Fig. 6. York Harbor, Maine. Diam. 42 mm. R. T. J. Coll., 781. $\times 3.8$. Partially tetramerous specimen. Ambulaerum IV fails to reach the apical disc, so that interambulacra 3 and 4 are in contact dorsally; there are five oculars and genitals, ocular III and genital 5 are split by median sutures (p. 170); extra genital pores occur, two of which are in interambulacrum 3. Page 44.
- Fig. 7. Massachusetts Bay. Diam. 37 mm. R. T. J. Coll., 780. $\times 2.8$. Partially tetramerous in that genital 4 is wanting, oculars IV, V are in contact, interambulacrum 4 dorsally has in part a single column of plates, as in *Arbacia*, Plate 4, fig. 11. Page 45.
- Fig. 8. The same specimen seen from within. $\times 2.8$. To show the partially single column of interambulacral plates in area 4. Page 45.
- Fig. 9. Sullivan, Maine. Diam. 14 mm. R. T. J. Coll., 661. $\times 5$. Completely tetramerous specimen; there are four teeth, eight primordial ambulacral plates, four ambulacral and interambulacral areas, four oculars and genitals. The absent parts are ocular and ambulaerum IV, the right half of interambulacrum 3, and the left half of interambulacrum 4. From this structural deficiency the right half of interambulacrum 4, which is related to ocular V, and the left half of interambulacrum 3, which is related to ocular III, come together and are in contact throughout their length. (Compare Plate 6, fig. 1, and Plate 7, fig. 2; text-fig. 218, p. 191.) Page 38.

Figs. 10-12. Locality (?) Peabody Museum, Salem. $\times 5.6$.

- Fig. 10. A normal spine to compare with Figs. 11, 12, which are abnormally inflated and rounded. A unique variant in the species and family. Page 78.

PLATE 7.

***Arbacia punctulata* (Lamarck).**

- Fig. 1. Woods Hole, Massachusetts. Diam. 11 mm. R. T. J. Coll., 785. $\times 3.8$. A partially tetramerous specimen; there are four ambulacra, but all other parts are in fives. Ambulacrum IV is wanting, so that interambulacra 3 and 4 are in contact throughout; extra interambulacral plates are developed as space fillers in this area. Page 41.

***Toxopneustes variegatus* (Lamarck).**

- Fig. 2. Tampa Bay, Florida. Measures 67 mm. through the axis II, 4. R. T. J. Coll., 749. $\times 1.9$. Partially tetramerous; five ambulacra and interambulacra ventrally, dorsally above the ambitus there are four ambulacra, interambulacra and oculars, but five genitals. Ocular II lies just below the ambitus and to it extend ambulacrum II, the right half of interambulacrum 1, and the left half of interambulacrum 2. Above this zone the left half of interambulacrum 1 and the right half of interambulacrum 2 are in contact to the apical disc, where they abut against oculars I and II as usual. (Compare p. 35; Plate 6, figs. 1, 9; text-fig. 218, p. 191.) Page 42.

***Strongylocentrotus dröbachiensis* (O. F. Müller).**

- Fig. 3. York Harbor, Maine. Diam. 37 mm. R. T. J. Coll., 662. $\times 5$. Almost completely tetramerous, with four teeth, eight primordial ambulacral plates, four ambulacra, and interambulacra, four oculars, but five genitals. Genital 1 is a depauperate imperforate plate lying between ocular I and genital 2. The absent parts are ocular and ambulacrum II, the right half of interambulacrum 1 and the left half of interambulacrum 2. Oculars I, V are insert as usual. An extra pore occurs in genital 4. (Compare Plate 6, figs. 1, 9.) Page 40.
- Fig. 4. York Harbor, Maine. Diam. 17 mm. R. T. J. Coll., 786. $\times 3.7$. Partially tetramerous; ventrally there are five teeth, ambulacra and interambulacra, dorsally only four ambulacra, but the interambulacra and other parts are in fives. Ocular II is imperforate, ambulacrum II exists for only a short distance ventrally, above which interambulacra 1 and 2 are in contact, and some extra interambulacral plates are developed as space fillers. An accessory plate (split off?) lies between oculars I, II and genitals 1, 5. Page 43.
- Fig. 5. York Harbor, Maine. Diam. 51 mm. R. T. J. Coll., 784. $\times 2.8$. Partially tetramerous; ventrally there are five teeth, in the corona five ambulacra, but only four interambulacra, also four oculars and genitals. Ocular II may be considered double as it has two pores related apparently to ambulacra I and II. There is no trace of interambulacrum 1; ambulacra I and II are in contact throughout their extent. Page 41.
- Fig. 6. Frenchman's Bay, Maine. Diam. 36 mm. R. T. J. Coll., 783. $\times 3$. Genital 3 is split by one horizontal suture, and genital 2 is split into three plates. (Compare Echinothuriidae.) Page 168.
- Fig. 7. Dumpling Islands, North Haven, Maine. Diam. 14 mm. R. T. J. Coll., 848. Completely hexamerous specimen, the apical disc. $\times 7.7$. Six ambulacra, interambulacra, oculars and genitals, but genitals 3 and 6 are fused. The added parts lie between oculars III and IV. (Compare Plate 6, fig. 2; Plate 8, fig. 3.) Page 47.
- Fig. 8. Same specimen, peristome. $\times 4$. There are six teeth, twelve primordial ambulacral plates and actinal cuts, six ambulacra and interambulacra. Page 47.

***Echinarachnius parma* (Lamarck).**

- Fig. 9. Chelsea Beach, Massachusetts. Diam. 60 mm. Boston Soc. Nat. Hist. Coll., 348. $\times 1.4$. Partially hexamerous; there are five ambulacra and interambulacra ventrally, six ambulacra and interambulacra dorsally; the added areas lie between interambulacrum 1 and ambulacrum II. In the basicoronal row the five primordial interambulacral plates and the ten primordial ambulacral plates are in place as usual. Of the latter, the Ia, IIa, IIIb, IVa, Vb are larger as usual by Lovén's law. Same specimen as photograph, Plate 8, fig. 4. Page 49.

PLATE 8.

Bothriocidaris pahleni Schmidt.

Page 242.

- Fig. 1. Diluvial-Geschichte, Ordovician, Rostov, Russia. Height 16.2 mm., diam. 16 mm., from a plaster cast, Mus. Comp. Zool. Coll. 3,082 (from R. T. J. Coll.). Original at Rostov. $\times 2$. Two columns of high hexagonal plates in each ambulacral area and one column of plates in each interambulacral area, the latter darkened for contrast. (Compare drawing of another specimen, Plate 1, fig. 3.)

Arbacia punctulata (Lamarek).

Page 39.

- Fig. 2. Woods Hole, Massachusetts. Almost completely tetramerous, but there are five genital plates. The wanting parts are a tooth and ocular II, with its associated parts, which are ambulacrum II, the left half of interambulacrum 2, and the right half of interambulacrum 1. Same specimen as Plate 6, fig. 1.

Strongylocentrotus dröbachiensis (O. F. Müller).

Page 47.

- Fig. 3. Dumpling Islands, North Haven, Maine. R. T. J. Coll., 838. Natural size. Completely hexamerous; structure exactly as in Plate 7, fig. 7. This specimen is oriented and the additional area calculated from the oculars I, V insert, the position of the madreporite and the fused genitals.

Echinarachnius parma (Lamarck).

Page 49.

- Fig. 4. Partially hexamerous. Natural size. Pentamerous ventrally, but a sixth ambulacrum and interambulacrum are added dorsally. Same specimen as Plate 7, fig. 9.

Archaeocidaris wortheni Hall.

Page 259.

- Fig. 5. St. Louis Group, Lower Carboniferous, St. Louis, Missouri, Amer. Mus. Nat. Hist. $\frac{7747}{1}$, cotype. Natural size. Ventral view, showing narrow ambulacral areas and four columns of plates in each interambulacrum. The basal terrace is clear on interambulacral plates. The peristome and lantern are in part preserved orally. This is one of the two most nearly complete specimens known in the genus. Drawings, Plate 9, figs. 6-8.

- Fig. 6. Same specimen. Dorsal view. Primary spines and lantern in place.

Archaeocidaris legrandensis Miller and Gurley.

Page 260.

- Fig. 7. Keokuk Group, Lower Carboniferous, Boonville, Missouri. Univ. of Chicago Coll., 8,855. $\times 1.5$. There are four columns of plates in each interambulacrum. Drawing, Plate 9, fig. 12.

- Fig. 8. Same locality. Museum and Cat. no. as fig. 7. $\times 1.5$. With primary and secondary spines in place. Drawing, Plate 9, fig. 13. These two specimens are the cotypes of *Eocidaris blairi* Miller, here considered a synonym.

Archaeocidaris newberryi Hambach.

Page 269.

- Fig. 9. St. Louis Group, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll. 8,119 (from G. Hambach Coll.), holotype. Natural size. Drawing, Plate 13, figs. 15a, 15b.

Archaeocidaris triserialis (M'Coy).

Page 275.

- Fig. 10. Arenaceous Limestone, Lower Carboniferous, Killycloghy, Lisbellow, County Tyrone, Ireland. Griffith Coll., Science and Arts Museum Coll., Dublin, holotype. Natural size. The specimen consists of spines only.

Figs. 1, 2, 4-9 photographed by F. A. Saunderson; fig. 3 photographed by H. W. Tupper; fig. 10 photographed in Dublin by A. C. Bridle.

PLATE 9.

Miocidaris keyserlingi (Geinitz).

Page 245.

- Fig. 1. Lower Zechstein, Permian, Corbusen, Germany (after Geinitz, 1848, Plate 7, fig. 2). Cotype. Natural size, and enlarged. Spine swollen, finely muricate.
- Fig. 2. Zechstein, Permian, Corbusen, Ronneburg, Germany. Dresden Museum, cotype. $\times 7.5$. Two columns of pentagonal plates in an interambulacrum. Redrawn from my sketch of the specimen in the Dresden Museum.
- Fig. 3. Permian, Humbleton Hill, England. Enlarged, after King, 1850, Plate 6, fig. 22, where in the description of the plate this figure, with the two following, are called *Palaechinus verneuili* King, and in the text they are called *Archaeocidaris verneuili* King. Cotype of that species (here considered a synonym).
- Fig. 4. Permian, Tunstall Hill, England. Spine. $\times 2.8$. After King, 1850, Plate 6, fig. 24. Cotype of *Archaeocidaris verneuili* King, here considered a synonym.
- Fig. 5. Probably referable to this species, Permian, Humbleton Hill, England. Enlarged. After King, 1850, Plate 6, fig. 24. Cotype of *Archaeocidaris verneuili* King, here considered a synonym.

Archaeocidaris wortheni Hall.

Page 259.

- Fig. 6. Same specimen as photographs, Plate 8, figs. 5, 6. Cotype. $\times 1.8$. Two columns of plates, all similar, in each ambulacral area and four columns of plates in each interambulacral area from the basicoronal row up. In the basicoronal row of the interambulacral areas the plates are nearly or quite whole plates, alternating with half-plates, due to ventral resorption. In areas A and C in this row, the plates of columns 1 and 4 are large and the plates of columns 3 and 2 small. On the contrary, in areas E and G in this row, the plates of columns 1 and 3 are small and the plates of columns 4 and 2 are large. (Compare fig. 8.) Ventrally pyramids are in place, and ambulacral with interradiar non-ambulacral peristomal plates are on the peristome. (Compare text-fig. 26, p. 70.)
- Fig. 7. The same, restored to show a complete peristome and basicoronal row of the corona. $\times 1.8$. (Compare text-figs. 47, p. 80; 239 bis, p. 264.)
- Fig. 8. The same restored, showing the ventral border of the corona as in fig. 7, and the plates which have been removed by resorption restored theoretically. In interambulacral areas A and C, column 4 originates to the right of the center, and in interambulacral areas E, G, and I, column 4 originates to the left of the center, thus producing the system of alternation of large and small plates seen in the basicoronal row of the several areas. (A similar occurrence of the initial plate of column 4 being on the left of the center, or on the right of the center is seen in *Melonechinus multiporus*, text-fig. 245, p. 382.)

Figs. 9-11. St. Louis Group, Lower Carboniferous, St. Louis, Missouri. Amer. Mus. Nat. Hist. $\frac{7+7+7}{1}$, cotypes, being part of the same lot as fig. 6.

- Fig. 9. Plates showing scrobicular ring, basal terrace, primary and secondary spines. $\times 1.9$.
- Fig. 10. Pyramid with epiphyses, brace and tooth, the last restored dorsally as indicated by dotted lines. $\times 3.6$.
- Fig. 11. Nearly entire primary spine, which is slender, smooth, terete, somewhat arcuate. $\times 1.9$.

Archaeocidaris legrandensis Miller and Gurley.

Page 260.

- Fig. 12. Same specimen as photograph, Plate 8, fig. 7. $\times 1.8$. Four columns of plates in each interambulacral area. The plates have a basal terrace well defined (see description of fig. 13).
- Fig. 13. Same specimen as photograph, Plate 8, fig. 8. $\times 3.7$. Part of the test with smooth, terete primary spines and small secondary spines in place. (These two specimens, figs. 12 and 13, are the cotypes of *Eocidaris blairi* Miller, here considered a synonym.)

Figs. 1-5 drawn by W. M. Barrows; figs. 6-13 by J. Henry Blake.

PLATE 10.

Archaeocidaris longispina Newberry.

Page 261.

- Fig. 1. Carboniferous (Coal Measures), North Arizona. Columbia Univ. Coll., 6,419 G, holotype. Natural size. Spines smooth, straight, inflated.

Archaeocidaris glabrispina (Phillips).

Page 261.

- Fig. 2. Lower Carboniferous, Hook Head, Ireland. Sedgwick Museum, Cambridge, England. a, spine $\times 1.9$; b, base of spine more enlarged. The spine is smooth, straight, inflated.

Archaeocidaris legrandensis Miller and Gurley.

Page 260.

- Fig. 3. Kinderhook Group, Lower Carboniferous. Le Grand, Iowa. Univ. of Chicago Mus. Coll., 12,314. $\times 3.7$. Four columns of plates in an interambulacral area, scrobicular ring well developed.

- Fig. 4. Same horizon and locality. Univ. of Chicago Coll., 6,198, holotype. $\times 1.8$. Interambulacral plates with smooth primary spines in place.

Archaeocidaris nereis (Münster).

Page 262.

- Fig. 5. Lower Carboniferous, cotypes, enlarged. $\times$ about 2. (After Münster, 1839, Plate 3, figs. 6a-6d.) a, an adradial interambulacral plate; b, spine; c, possibly a brace of the lantern; d, a left half-pyramid.

Figs. 6, 7. After Müller, 1857, Plate 3, figs. 12, a, b. $\times 2.7$.

- Fig. 6. Pyramid, face view, moderately deep foramen magnum (p. 363).

- Fig. 7. Pyramid in side view with ridges for the attachment of interpyramidal muscles.

Archaeocidaris glabrispina (Phillips).

Page 261.

- Fig. 8. Lower Carboniferous, Limestone, Ireland (after Bailly, 1877, p. 18, figs. a-e). Cotypes of *Archaeocidaris stellifera* Bailly, here considered a synonym. Details of plate ornamentation in figs. a-c are very doubtful; d, spine, smooth, swollen; e, base of same enlarged.

- Fig. 9. Lower Carboniferous, Miatschkowa, near Moscow, Russia (after Trautschold, 1879, Plate 2, fig. without a number). The holotype of *Archaeocidaris laevis* Trautschold, here considered a synonym. Spine smooth, inflated.

Archaeocidaris rossica (Buch).

Page 263.

- Fig. 10. Lower Carboniferous, Miatschkowa, Province of Moscow, Russia. Palaeontological Museum, Munich. $\times 1.8$. Same specimen as Plate 11, figs. 1, 2, spread out on the Lovén method. Ambulacra conform to the outline of the interambulacra, four columns of plates in each interambulacrum. Interambulacral plates are high hexagonal, elongating dorsally. Basal terrace developed, but wanting in the younger plates dorsally; primary tubercles imperforate in younger plates dorsally, and in the youngest plates there is no tubercle developed. In areas A, G, and I, the plates of the basicoronal row from left to right (of the area) are in the sequence of a large plate, small plate; large plate, small plate. Therefore column 4 lies to the right of the center. In areas C and E, on the contrary, the sequence from left to right is a small plate, then a large one; another small plate and a large one. In this arrangement column 4 lies to the left of the center. This relation of the sequence of large and small plates in the basicoronal row, and its relation to the position of column 4 will be understood by the schematic figure, Plate 9, fig. 8, where the plates removed by resorption are restored in accordance with the rules observed in other Palaeozoic Echini. Strongly inbricating scale-like ambulacral and non-ambulacral plates occur on the peristome. (See text-fig. 239 bis, p. 264.)

Archaeocidaris sixi Barrois.

Page 447.

- Fig. 11. Carboniferous, Assize de Leña, Ontoria, Seburga, Spain. Cotypes (after Barrois, 1882, Plate 16, figs. 5a-5c). a, b, interambulacral plate in face and side views. $\times 0.9$. c, spine, flattened, vertically striate, the form of the cross section is shown above. $\times 2.8$. On account of the small size and flattening, this is apparently a secondary, not a primary spine.

Archaeocidaris pizzulana Gortani.

Page 273.

- Fig. 12. Carboniferous, Forca Pizzul, Carnic Alps, Italy, cotypes (after Gortani, 1905, Plate 15, figs. 29, 30, 31, 33). a, b, interambulacral plates; c, primary spine with thorn-like spinules set opposite one another. $\times 0.9$. d, base of spine showing annulus.

Figs. 5 and 9 drawn by W. M. Barrows; all others by J. Henry Blake.

PLATE 11.

Archaeocidaris rossica (Bueh).

Page 263.

Figs. 1-5. Lower Carboniferous, Miatschkowa, Province of Moscow, Russia.

- Fig. 1. Ventral view of a nearly perfect specimen. Diameter through A, F, 46 mm. Palaeontological Museum, Munich. $\times 2$. Ambulacra are best preserved in areas H and J, four columns of plates in each interambulacral area. Interambulacral plates are higher than wide, increasing in height to the ambitus. Basal terrace moderately strong, with large scrobicular area (seen better in fig. 4); the flange bearing secondary tubercles, is wider in the ventral and dorsal portion of each plate. On the peristome there are many small scale-like imbricating ambulacral and interradial non-ambulacral plates.
- Fig. 2. Same specimen, dorsal view. $\times 2$. Interambulacral plates are much higher than ventrally, the basal terrace is wanting dorsally, although the tubercles are well developed, still further dorsally as seen in a plate in column 3 of area C, the young tubercle is imperforate, as in young tubercles of recent *Cidaridae*, Plate 3, figs. 1, 2. In the youngest interambulacral plates, seen best in area I, no tubercle is yet developed. Within the center are many small periproctal plates. This, which is shown spread out on the Lovén method in Plate 10, fig. 10, is the most complete specimen known in the genus.
- Fig. 3. The same. $\times 8$. Enlargement of periproctal plates; the two larger plates are possibly ocular and genital, from area D of fig. 2.
- Fig. 4. Interambulacral plate showing perforate mamelon, sunken platform, with its elevated ring-like parapet, the boss bounded by the basal terrace, and a rather wide scrobicule within the scrobicular circle. On the margin of the plate are secondary and miliary tubercles. Secondary spines are vertically finely striate and miliary spines are in place; these are the only miliary spines so far known in specimens of the genus. Mus. Comp. Zoöl. Coll., 3,088 (from R. T. J. Coll.). $\times 4$.
- Fig. 5. Base of primary spine, showing milled ring, fine vertical striation, and nodose spinules. Mus. Comp. Zoöl. Coll., 3,091 (from R. T. J. Coll.). $\times 4$. (Compare Plate 12, figs. 13a-13k.)

Figs. 1-3 drawn by Anton Birkmaier; figs. 4, 5 drawn by J. Henry Blake.

PLATE 12.

Archaeocidaris rossica (Buch).

Page 263.

Figs. 1-13. Lower Carboniferous. Miatschkowa, Province of Moscow, Russia.

- Fig. 1. Mus. Comp. Zoöl. Coll., 3,086 (from R. T. J. Coll.). $\times 4$. Dorsal view of two half-pyramids with epiphyses, brace, and compass in place; this is the most nearly perfect specimen of a compass seen from the Palaeozoic (p. 182).
 Fig. 2. The same restored.
 Fig. 3. Mus. Comp. Zoöl. Coll., 3,084 (from R. T. J. Coll.). $\times 4$. Face view of the upper part of two half-pyramids with epiphyses and a brace in place. The space between the half-pyramids, which is occupied by the interpyramidal muscle, is narrower than normal because the half-pyramids are somewhat out of place, compare fig. 5.

Figs. 4-6. A very fine lantern in the Palaeontological Museum, Munich.

- Fig. 4. Pyramid face view. $\times 4$. Braces and tooth in place, foramen magnum moderately deep.
 Fig. 5. Ventral view. $\times 4$. The pyramids curve laterally, giving spaces for long interpyramidal muscles, the lantern is strongly inclined, as is obvious from the amount of the pyramids seen from this view.
 Fig. 6. The same specimen, dorsal view. $\times 4$. Epiphyses, braces, and teeth in place, the foramina magna moderately deep. (Figs. 4-6, compare text-fig. 208, p. 184.)
 Fig. 7. Mus. Comp. Zoöl. Coll., 3,085 (from R. T. J. Coll.). Upper part of two half-pyramids, in sidewise view. $\times 4$. Epiphyses, brace, and tooth in place; *p. s.*, pyramidal suture.
 Fig. 8. Mus. Comp. Zoöl. Coll., 3,086 (from R. T. J. Coll.). $\times 4$. Pyramid, side view, showing ridges for the attachment of interpyramidal muscle, epiphysis with glenoid cavity, a displaced brace, and a tooth, the latter restored ventrally, as indicated by dotted lines.
 Fig. 9. Mus. Comp. Zoöl. Coll., 3,087 (from R. T. J. Coll.). $\times 8$. Ambulacral plates with an adjacent adradial plate. The ambulacral plates bevel strongly under the adradials as seen on the right. On the left the ambulacrum is pushed out of place under the adradial plate. Outline of ambulacrum undulate, conforming to the outline of the interambulacrum. (Compare Plate 10, fig. 10.)
 Fig. 10. The same, ambulacral plate, in side view to show the adradial bevel. $\times 4$.
 Fig. 11. Mus. Comp. Zoöl. Coll., 3,084 (from R. T. J. Coll.). $\times 4$. A plate not in place, perhaps a genital, seen from the interior.
 Fig. 12. Mus. Comp. Zoöl. Coll., 3,087 (from R. T. J. Coll.). Natural size. Test, ventral view. The limit of the upper part of the figure is about on the line of the ambitus.
 Fig. 13. Mus. Comp. Zoöl. Coll., 3,091. Natural size. Primary spines, showing their form and spinules. (Compare Plate 11, fig. 5.)

Figs. 1-3 and 7-11 drawn by J. Henry Blake; figs. 4-6 drawn by Anton Birkmaier; photographs by F. A. Saunderson.

PLATE 13.

Archaeocidaris agassizi Hall.

Page 266.

Figs. 1-4. Burlington Limestone. Lower Carboniferous, Burlington, Iowa.

- Fig. 1. After Hall, 1858, Plate 26, figs. 1b, 1c, 1d. Cotypes. a, plate enlarged, basal terrace clear; b, the same in profile; c, spine, which is elliptical in cross section. $\times 1.8$.
 Fig. 2. Univ. of Michigan Coll., 1,580. $\times 3.8$. Pyramid with tooth in place, the pyramid dorsally and the tooth ventrally and dorsally are restored as indicated by dotted lines.
 Fig. 3. F. Springer Coll., 8,100. $\times 1.8$. Showing ambulacra, and four columns of interambulacral plates in area I; a few ambulacral plates are on the peristome.
 Fig. 4. F. Springer Coll., 8,087. $\times 3.7$. Ambulacral plates with lateral bevel, interambulacral plates, pyramid with epiphyses and brace. The perforated, elongate plates are unlike anything seen in other species; they may be genitals.

Archaeocidaris illinoisensis Worthen and Miller.

Page 266.

- Fig. 5. St. Louis Group, Lower Carboniferous, near Illinois Furnace, Hardin County, Illinois (after Worthen and Miller, 1883, Plate 31, fig. 1a, pars, fig. 1b). Cotypes. $\times 0.9$. Spines swollen, with fine spinules.

Archaeocidaris coloradensis nom. nov.

Page 267.

- Fig. 6. Crinoidal Limestone, Upper Carboniferous, Northern Arizona. Columbia Univ. Coll., 6,900 G, cotype. $\times 0.9$. Fragment from shaft of a primary spine, muricate.

Archaeocidaris keokuk Hall.

Page 267.

- Fig. 7. Keokuk Group, Lower Carboniferous, Warsaw, Illinois, (after Hall, 1858, Plate 26, figs. 2a, 2b) cotypes. a, plate enlarged, shows basal terrace; b, spine slightly enlarged, with numerous fine spinules.

Archaeocidaris gracilis Newberry.

Page 267.

- Fig. 8. Crinoidal Limestone, Upper Carboniferous, Cañon, Diamond River (Colorado?). Columbia Univ. Coll., 603 and 604, holotype. $\times 0.9$. Spine slender, bears fine spinules.

Archaeocidaris aculeata Shumard.

Page 268.

- Fig. 9. Topeka Limestone, Carboniferous (Coal Measures), Topeka, Kansas. Indiana Univ. Geological Survey Coll. $\times 1.9$. a, b, dissociated plates; c-f, spines with small irregularly placed spinules.

Archaeocidaris shumardana Hall.

Page 268.

- Fig. 10. Warsaw Limestone, Lower Carboniferous, Warsaw, Illinois (after Hall, 1858, Plate 26, figs. 3b-3d). Cotypes, a, plate enlarged; b, same in profile; c, spines with fine spinules. $\times 1.9$.

Archaeocidaris edgarensis Worthen and Miller.

Page 269.

- Fig. 11. Upper Coal Measures, one mile east of Baldwinville, Edgar County, Illinois (after Worthen and Miller, 1883, Plate 30, figs. 15a-15c). Cotypes. a, single plate; b, spine; c, base of spine, enlarged.
 Fig. 12. Junietta Group, Carboniferous (Coal Measures), Manhattan, Kansas. J. W. Beede Coll. $\times 2.8$. A right half-pyramid, face view, epiphysis wanting; p. s., pyramidal suture.
 Fig. 13. Same specimen, side view, with ridges for the attachment of interpyramidal muscle. $\times 2.8$.
 Fig. 14. Same specimen, inner view, showing pyramidal suture and dental slide. $\times 2.8$.

Archaeocidaris newberryi Hambach.

Page 269.

- Fig. 15. Lower St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll., 8,119 (from G. Hambach Coll.), holotype. $\times 1.8$. a, plates with primary and secondary spines in place; b, a nearly perfect primary spine, spinules directed distally, in series. Same specimen as photograph, Plate 8, fig. 9.

Archaeocidaris tridifer White.

Page 269.

- Fig. 16. Red Wall Limestone, Carboniferous (Coal Measures), Camp Apache, Navajo County, Arizona (after White, 1877, Plate 6, figs. 8a, 8b). U. S. Nat. Mus. Coll., 8,471, cotypes. $\times 0.9$. a, hexagonal interambulacral plate; b, primary spine, restored proximally and distally as indicated; spinules directed distally, irregularly distributed.

Figs. 2-4, 8, 9, 12-15, drawn by J. Henry Blake; all others copied by W. M. Barrows.

PLATE 14.

Archaeocidaris norwoodi Hall.

Page 270.

- Fig. 1. Kaskaskia Group, Lower Carboniferous, Chester, Illinois (after Hall, 1858, Plate 26, figs. 5b-5e), cotypes. a, adambulacral plate enlarged; b, the same in profile; c, spine nearly twice enlarged; d, base of same more enlarged; spinules small, or large, directed distally.

Archaeocidaris paradoxa (Eichwald).

Page 270.

- Fig. 2. Upper Carboniferous, Sterlitamak and Saraninsk, Ural (after Eichwald, 1860, Plate 32, fig. 25), cotype. $\times 0.9$. Shaft of spine, spinules large, directed distally.

Archaeocidaris mucronata Meek and Worthen.

Page 271.

- Fig. 3. Chester Group, Lower Carboniferous, Liberty, Randolph County, Illinois (after Meek and Worthen, 1866, Plate 23, figs. 3a, 3c), holotype. $\times 0.9$. a, hexagonal interambulacral plate from a median column; b, spine with large spinules directed distally.
- Fig. 4. Upper Carboniferous, ten miles west of Ojo del Oso, near Fort Wingate, New Mexico (after White, 1877, Plate 6, fig. 7a, where it is referred to *A. ornatus* Newberry). U. S. Nat. Mus. Coll. 8,472. $\times 0.9$. Distally and proximally restored as indicated by dotted lines.

Archaeocidaris dininnii White.

Page 271.

- Fig. 5. Upper Coal Measures, near Tecunseh, Nebraska (after White, 1880a, Plate 35, figs. 6a, 6b). U. S. Nat. Mus. Coll. 8,031, cotypes. $\times 0.9$. a, b, primary spines, with spinules at right angle to the axis.

Archaeocidaris cratis White.

Page 272.

- Fig. 6. Upper Carboniferous, confluence of Grand and Green Rivers, Utah (after White, 1880a, Plate 33, fig. 2a, by error given as White, 1880, on my p. 272). U. S. Nat. Mus. Coll., 8,235, holotype. $\times 0.9$. Spinules sparse, but large, directed distally.

Archaeocidaris acanthifera Trautschold.

Page 272.

- Fig. 7. Lower Carboniferous, Miatschkowa, near Moscow (after Trautschold, 1879, Plate 2, fig. 1n, the number is omitted on the Plate, but occurs in the description of the same, by error given as Plate 2, fig. 1u on my p. 272). Holotype. Spinules irregularly distributed, long.
- Fig. 8. Probably referable to this species. Carboniferous (Coal Measures), marine band, below the Gin-Mine coal, Nettlebank, North Staffordshire, England (after Hind, 1905, Plate 35, figs. 1, 1a, by error given as Plate 25 on my p. 272). Natural size. Spinules long.

Archaeocidaris biangulata Shumard and Swallow.

Page 273.

- Fig. 9. Huerco Formation, Carboniferous (Coal Measures), Diablo Mountains, Western Texas. U. S. Nat. Mus. Coll. $\times 2.8$. a, adradial plate, basal terrace prominent; b, primary spine with serrate lateral flanges passing into spinules which distally are generally distributed; c, similar, but flange more pronounced; d, flange still wider.

Archaeocidaris ornata (Eichwald).

Page 274.

- Fig. 10. Lower Carboniferous, Miatschkowa, near Moscow (after Eichwald, 1860, Plate 32, fig. 24). Holotype. Spine densely covered with small spinules directed distally.

Archaeocidaris ourayensis Girty.

Page 274.

- Fig. 11. Hermosa Formation, Carboniferous (Coal Measures), Ouray, Colorado (after Girty, 1903, Plate 1, fig. 14). Holotype. U. S. Nat. Mus. Coll., 35,369. Somewhat enlarged. Spine densely covered with large spinules, directed distally.

Archaeocidaris triplex White.

Page 274.

- Fig. 12. Carboniferous (Coal Measures), near Taos, New Mexico (after White, 1881, Plate 4, figs. 3a-3c), cotypes. U. S. Nat. Mus. Coll. 9,449. $\times 0.9$. a, small interambulacral plate, "probably this species"; b, spine triangular in section with spinules in three series, directed distally. White says this figure is restored from fragments; c, section of spine.

PLATE 14 (continued).

Archaeocidaris megastyla Shumard and Swallow.

Page 273.

- Fig. 13. St. Louis Group, Lower Carboniferous, St. Louis, Missouri. U. S. Nat. Mus. Coll., 43,009. $\times 0.9$. Interambulacral plates with primary and secondary spines in place, the primary having strong, thorn-like, widely spaced spinules.

Archaeocidaris triserialis (M'Coy).

Page 275.

- Fig. 14. Arenaceous Limestone, Lower Carboniferous, Killybegh, Lisbellow, County Tyrone, Ireland (after M'Coy, 1844, Plate 26, fig. 1). Griffith Collection, Science and Arts Mus. Coll., Dublin. Holotype. $\times 0.9$. Spines with three series of serrate spinules directed distally. Same specimen as photograph, Plate 8, fig. 10.

Archaeocidaris triserrata Meek.

Page 275.

- Fig. 15. Upper Carboniferous, near Omaha, Nebraska (after Meek, 1872, Plate 1, figs. 6a-6c). U. S. Nat. Mus. Coll. 6,599. Cotypes. a, base of spine, $\times$ about 4; b, c, spines with serrate spinules, enlarged a little less than $\times 2$.

Archaeocidaris urii (Fleming).

Page 276.

- Fig. 16. Lower Carboniferous, Ireland (after Portlock, 1843, Plate 16, fig. 11, who figured it as *Cidaris vetusta*). Interambulacral plate. Natural size. (Probably the specimen in the Jermyn Street Museum, 7,768, see p. 278.)

Archaeocidaris wervekei Tornquist.

Page 276.

- Fig. 17. Lower Carboniferous, Hunsrück, Germany (after Tornquist, 1897, Plate 22, figs. 2a, 2b, 3, 9, 10). Cotypes. a, hexagonal interambulacral plate, natural size; b, the same, enlarged, basal terrace pronounced; c, an adradial plate enlarged; d, a plate in profile; e, f, spine natural size, and detail enlarged, with nodose spinules, arranged in vertical series.

Archaeocidaris urii (Fleming).

Page 276.

- Fig. 18. Lower Carboniferous, Ireland (after M'Coy, 1844, Plate 27, fig. 1).

- Fig. 19. Lower Carboniferous, Hayfod-y-Calch, Corwen, Wales; Sedgwick Museum, Cambridge (after Keeping, 1876, Plate 3, figs. 14, 15, 18). $\times 0.9$. a, dissociated plates as they occur on the slab; b, an adradial plate, basal terrace clearly defined; c, a peculiar plate of unknown nature from fig. a, enlarged (p. 278).

- Fig. 20. Lower Carboniferous, Benburb, County Tyrone, Ireland (for the locality of this specimen see discussion, p. 278), (after Portlock, 1843, Plate 16, figs. 10a-10d, where it is called *Cidaris benburbensis* Portlock, of which species it is the holotype). Museum of Practical Geology Coll., London, 7,659. a, spine, natural size and enlarged; b, c, plates, natural size.

Figs. 9 and 13 drawn by J. Henry Blake; all others copied by W. M. Barrows.

PLATE 15.

Archaeocidaris urii (Fleming).

Page 276.

- Fig. 1. Lower Carboniferous, Knock Hill Quarry, Fife, Scotland. Museum of Practical Geology, London, 16,319. $\times 1.8$. Showing coronal ambulacral plates and four columns in an interambulacrum, also some peristomal plates.
 Fig. 2. Lower Carboniferous, Hunsrück, Germany (after Tornquist, 1897, Plate 23, fig. 4). a, b, c, spine. $\times 0.9$ and enlarged. Spinules pronounced, in series, directed distally.
 Fig. 3. Culm, Lower Carboniferous, Königsberg, Germany (after Parkinson, 1903, Plate 15, fig. 13). The holotype of *Archaeocidaris regimontana* Parkinson, here considered a synonym. A single interambulacral plate.

Archaeocidaris halliana (Geinitz).

Page 279.

- Fig. 4. Upper Carboniferous, Nebraska City, Nebraska (after Geinitz, 1866, Plate 5, figs. 1a, 1b, 2a, 2b). Cotypes. a, interambulacral plate, natural size and enlarged; b, spine enlarged $\times$ about 6. c, same much enlarged, with minute spinules in numerous vertical series.

Archaeocidaris muensteriana (Koninck).

Page 280.

- Fig. 5. Lower Carboniferous, Visé, Belgium (after Koninck, 1842-'44, Plate E, figs. 2a-2d). Cotypes. a, plate, $\times 0.9$, and enlarged; b, spine, $\times 0.9$; c, base of same enlarged, with minute spinules in numerous vertical series.

Archaeocidaris forbesiana (Koninck).

Page 280.

- Fig. 6. Productus Limestone, Salt Range, Permian, near Katta, Golawali, and Bazarwan, India (after Waagen, 1879-'87, Plate 95, figs. 5a, 7a, 13b, 14, 15). Natural size. a, b, imperfect interambulacral plates, c, base of spine; d, e, spines (cotypes), which are inflated with minute spinules in vertical series.

Archaeocidaris spinoclavata Worthen and Miller.

Page 281.

- Figs. 7a-7e. Middle and Lower Coal Measures, St. Clair and Marshall Counties, Illinois (after Worthen and Miller, 1883, Plate 30, figs. 14a, 14b, 14c). Cotypes. Plates hexagonal; spine distally enlarged, densely spinulose.
 Figs. 7f-7h. After Meek and Worthen, 1873, Plate 24, figs. 13a, 13d, 13e, who figured them as *Archaeocidaris* (?) sp. Spines inflated, densely spinulose.

Archaeocidaris clavata (Eichwald).

Page 282.

- Fig. 8. Carboniferous, Yegorjefsk, Province of Kalonga, Russia (after Eichwald, 1860, Plate 33, fig. 16). By error given as Plate 23 on my p. 282. Holotype. Spine, inflated.

Archaeocidaris selwyni R. Etheridge, Jr.

Page 447.

- Fig. 9. Nowra Grit, Permo-Carboniferous, Nowra, Shoalhaven River, County St. Vincent, New South Wales (after R. Etheridge, Jr., 1892a, Plate 15, fig. 3) from casts of part of the plates of the holotype. $\times 0.9$.
 Fig. 10. Upper Marine Series, Permo-Carboniferous, Dagworth, about five miles south of West Maitland, County Northumberland, New South Wales (after R. Etheridge, Jr., 1892a, Plate 22, fig. 1 in part). Etheridge considered this distinct from *A. selwyni*. Natural size. Four columns of plates in an interambulacral area.

Eocidaris laevispina (Sandberger).

Page 255.

- Fig. 11. Middle Devonian, Villmar (after Bather, 1909, Plate 1, figs. 1-4). Enlarged. a, b, c, interambulacral plates; d, base of spine. a, the original of Sandberger's, 1855-'56, Plate 35, fig. 2b; b, the original of Sandberger's Plate 35, fig. 2; c, selected by Bather as the lecto-holotype, the original of Sandberger's Plate 35, fig. 2a; d, base of primary spine, the original of Sandberger's Plate 35, fig. 2d. None of the plates shows a basal terrace.
 Fig. 12. Middle Devonian, Villmar (after Bather, 1909, Plate 1, fig. 5). Enlarged. The holotype of *Cidaris scrobiculata* Sandberger, here considered a synonym, the original of Sandberger's, 1855-'56, Plate 35, fig. 3. No basal terrace.

Archaeocidaris konincki Desor.

Page 446.

- Fig. 13. Lower Carboniferous, Tournay, Belgium (after Desor, 1858, Plate 21, figs. 7-10). Cotypes. Imperfectly known.

Archaeocidaris trautscholdi Tornquist.

Page 448.

- Fig. 14. Lower Carboniferous, Miatschkowa, near Moscow (after Tornquist, 1896, Plate 4, fig. 1). Holotype. Plate seen from within. Imperfectly known.

Archaeocidaris ladina Stache.

Page 446.

- Fig. 15. Bellerophonkalke, Lower Carboniferous, St. Martin, South Tyrol (after Stache, 1877, Plate 5, fig. 11b). Cotypes. Enlarged. Base of spine and pieces of spines with short spinules. Imperfectly known.

Echinocrinus striatus Eichwald.

Page 450.

- Fig. 16. Dolomitic Limestone, Bogosłowski, Ural (after Eichwald, 1860, Plate 33, fig. 17). Holotype. Enlarged. Practically unrecognizable.

Fig. 1 drawn by A. T. Hollick; figs. 11, 12 copied by J. Henry Blake; all other figures copied by W. M. Barrows.

PLATE 16.

Lepidocidaris squamosa Meek and Worthen.

Page 282.

- Fig. 1. Lower Burlington Limestone, Lower Carboniferous, Burlington, Iowa. Mus. Comp. Zool. Coll., 3,026. Holotype. Natural size. Every third ambulacral plate is higher than the intermediate plates; eight columns of interambulacral plates in area A. Drawings, Plate 17, figs. 1-5.
- Fig. 2. Same horizon and locality, F. Springer Coll., 8,096. Natural size. Six columns of interambulacral plates in area A, primary spines in place. Drawings, Plate 17, figs. 7, 8, 10, 12, 14.
- Fig. 3. Same horizon and locality, F. Springer Coll., 8,098. Natural size. Very clear for the surface characters of interambulacral plates.

Echinocystites pomum Wyville Thomson.

Page 252.

- Fig. 4. Lower Ludlow, Silurian, Leintwardine, England, Museum of Practical Geology Coll., London, 7,385. (Original specimen of Sir Wyville Thomson's, 1861, Plate 3, fig. 3.) Cotype. Natural size. A ventral view, the outline of the ambulacral and interambulacral areas clearly defined. Tubercles and spines are visible on the interambulacra and an excellent lantern is in place.

Lepidocentrus drydenensis (Vanuxem).

Page 288.

- Fig. 5. Chemung Group, Upper Devonian, Dryden, New York. New York State Museum Coll., 4,200. Holotype. Natural size. The specimen is an internal mold of the ventral side, combined with some external features as spines. Drawings, Plate 21, figs. 1-3. On the same slab are additional incomplete impressions of other specimens of this species; these, with that figured, are the only known specimens of the species.

Fig. 1 from photograph by H. W. Tupper; figs. 2, 3, 5 by F. A. Saunderson; fig. 4 by J. W. Tutecher in London.

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PLATE 17.

Lepidocidaris squamosa Meek and Worthen.

Page 282.

Figs. 1-14. Lower Burlington Limestone, Lower Carboniferous, Burlington, Iowa.

Figs. 1-5. Mus. Comp. Zoöl. Coll., 3,026. Same specimen as photograph, Plate 16, fig. 1. Holotype.

- Fig. 1. $\times 0.9$. Eight columns of interambulacral plates in area A, the seventh and eighth columns coming in below the mid-zone.
- Fig. 2. Ambulacral detail from the area marked X in fig. 1. $\times 3.7$. Every third ambulacral plate is wider and higher than the intermediate plates.
- Fig. 3. Ambulacral detail from area marked XX in fig. 1, from nearer the mid-zone than is fig. 2. $\times 3.7$. Every third plate higher and wider than the intermediate plates. In cases, some intermediate plates may be demi- or occluded instead of all plates being primaries. (Compare fig. 7.) Primary tubercles of interambulacral plate perforate, with wide scrobicule, but no basal terrace.
- Fig. 4. Plates from the upper part of ambulacral area B to show beveling dorsally, and laterally under the interambulacrum. $\times 3.7$.
- Fig. 5. Dental pyramid. $\times 2$. Epiphysis wanting; corrugations present for the attachment of the interpyramidal muscle.
- Fig. 6. Mus. Comp. Zoöl. Coll., 3,046. $\times 2$. Dental pyramid, face view, foramen magnum moderately deep; the sutural face for the epiphysis occurs on the left.
- Fig. 7. F. Springer Coll., 8,096; same specimen as photograph, Plate 16, fig. 2. $\times 1.9$. Every third ambulacral plate higher, wider, and apposed to two plates of the opposite half-area. Adradial plates are much narrower than interambulacral plates of the median columns.
- Fig. 8. Same specimen. $\times 7$. Detail of typical ambulacral plates. A relatively high plate in one half-area is opposed to two lower plates of the opposite half-area.
- Fig. 9. F. Springer Coll., 8,074. $\times 3.7$. Interambulacrum with six columns of plates. There are four columns ventrally, the fifth and sixth columns coming in higher up. Ventrally there are some ambulacral plates which are evidently peristomal and in the middle line the tip of a tooth in place.
- Fig. 10. Same specimen as fig. 7. $\times 3.7$. Details of interambulacral plates with primary and secondary spines in place. There is no basal terrace around the primary tubercles; the lines in the figure that might be taken to indicate that structure are intended to represent the elevation of the boss.
- Fig. 11. F. Springer Coll., 8,095. $\times 1.8$. Six columns of plates in two interambulacral areas, adambulacral plates are narrower, primary spines in place.
- Fig. 12. Same specimen as fig. 7, showing the character of ambulacral and interambulacral plates and the bases of primary spines. $\times 3.7$.
- Fig. 13. Mus. Comp. Zoöl. Coll., 3,046. $\times 1.9$. Complete primary spines.
- Fig. 14. F. Springer Coll., 8,096. Same specimen as fig. 7. $\times 3.6$. Primary and secondary spines, showing their cylindrical character and fine vertical striae.

PLATE 18.

Palaeodiscus ferox Salter.

Page 250.

- Fig. 1. Lower Ludlow, Silurian, near Ludlow, England. British Mus. Coll., E 1,255. $\times 3.7$. An external sandstone mold of the ventral side. Ambulacra relatively broad ventrally; there are ambulacral pores ventrally as usual in Echini. Interambulacral plates irregular, faint in definition; impression of spines; and lantern in place in which latter can be discerned the impressions of braces and epiphyses.
- Fig. 2. Lower Ludlow, Silurian, Church Hill, Leintwardine, England. British Museum Coll., E 1,252. $\times 3.7$. An external sandstone mold of the ventral side. Ambulacral plates only on the peristome. Ambulacral plates in the corona have pore-pairs ventrally.
- Fig. 3. Same specimen. Mold of the exterior. $\times 15$. Ambulacral pores are in about the middle of each plate, fine spines on the interambulacral plate.
- Fig. 4. Same specimen, impression of the interior. $\times 15$. Shows ambulacral pores in the median line of each plate and a lateral extension of ambulacral plates beneath the interambulacral areas on either side.
- Fig. 5. After Sollas, 1899, fig. 7, p. 702, enlarged. Dorsal view, showing compasses, braces, and epiphyses. Original in Oxford University Museum.

Echinocystites pomum Wyville Thomson.

Page 252.

- Fig. 6. Lower Ludlow, Silurian, Leintwardine, near Ludlow (after Gregory, 1897, Plate 7, fig. 4). $\times 0.9$. Shows ambulacra and interambulacra with spines and a madreporite.
- Fig. 7. After Gregory, 1897, fig. 1, p. 125. Ambulacral plates of a half-area, much enlarged.
- Fig. 8. After Gregory, 1897, fig. 2, p. 125. Pyramid "seen from behind," enlarged.

Figs. 1-4 drawn from nature, and figs. 5, 6 copied by J. Henry Blake; figs. 7, 8 copied by W. M. Barrows.

PLATE 19.

Koninckocidaris silurica sp. nov.

Page 285.

- Fig. 1. From base of Rochester Shale, about ten feet above the Irondequoit Limestone, Niagara Group, Upper Silurian, ravine of the Genesee River, northern part of Rochester, New York. A. W. Giles, collector, 1909. Rochester University Coll. Holotype. Natural size. Of special interest as by far the geologically oldest echinoid yet found in America. Test viewed from the interior, ambulacral plates are high, about three equaling the height of an ambulacral plate. Ambulacral plates bevel over the interambulacrals and imbricate dorsally, as this is an internal view. Pores are near the middle of the ambulacral area, a quite usual character of the interior. Eight columns of nearly rhombic plates in an interambulacral area, all of which extend to the apical disc. All interambulacral plates imbricate ventrally and toward the center, nearly covering column 7, which shows only as very narrow plates. This is because it is an internal view. (For imbrication and beveling of ambulacral and interambulacral plates seen from the interior and exterior, see text-figs. 32-37, p. 75.) Drawings, Plate 20, figs. 5, 6.

Lepidocentrus mülleri Schultze.

Page 289.

- Fig. 2. Middle Devonian, Muhlenberg, near Gerolstein, Prussia. Mus. Comp. Zoöl. Coll., 3,040 (from F. Schultze Coll.), holotype. Natural size. Ambulacra narrow, plates low. Interambulacrum A with 11 columns of nearly rhombic plates imbricating dorsally and from the center laterally. Columns 5, 6, 9, 10, and 11 of area A drop out dorsally. Drawings, Plate 20, figs. 8-10.
- Fig. 3. Middle Devonian, Gerolstein, Prussia. Palaeontological Museum, Munich. Natural size. Interambulacral plates nearly rhombic, imbricating strongly; small primary and secondary tubercles and some spines in place. These two figs. (2, 3) are the most nearly complete specimens known in the species.
- Fig. 4. A plate from the same specimen, to show a perforate eccentric primary tubercle with scrobicule and secondary tubercles. $\times 3$.
- Fig. 5. Same specimen. a, secondary spine, $\times 5$, and b, primary spine, $\times 5$; c, secondary spine, $\times 10$. The spines are enlarged at the base, vertically very finely striate, nearly cylindrical as far as shown, but complete spines taper to a point distally.

Lepidocentrus whitfieldi sp. nov.

Page 290.

- Fig. 6. Waverly Group, Lower Carboniferous, Licking County, Ohio. Amer. Mus. Nat. Hist. Coll., 6,391, holotype, Natural size. Ventral view, about spherical in form, but flattened ventrally, ambulacral areas narrow. Drawing, Plate 21, fig. 4.
- Fig. 7. Same specimen, dorsal view. Drawing, Plate 21, fig. 5.

Hyattechinus pentagonus sp. nov.

Page 295.

- Fig. 8. Waverly Group, Lower Carboniferous, Meadville, Pennsylvania. Mus. Comp. Zoöl. Coll., 3,108 (from R. T. J. Coll.), paratype. Natural size. External sandstone mold of the dorsal side; ambulacra narrow, fourteen columns of plates in each interambulacrum. The apical disc measures about 9 mm. in diameter, and the test about 57 mm. in diameter. The apical disc therefore measures proportionately about 16 % of the diameter of the test.

Figs. 1, 2, 8 from photographs by H. W. Tupper; figs. 6, 7 by F. A. Saunderson; figs. 3-5 drawn by Anton Birkmaier.

PLATE 20.

Echinocystites pomum Wyville Thomson.

Page 252.

Figs. 1-4. Lower Ludlow, Silurian, Leintwardine, England.

- Fig. 1. After Wyville Thomson, 1861, Plate 4, fig. 3. Cotype. $\times 0.9$. Ambulacra narrow, the anal area (?) lies dorsally in an interambulacral area. Jaws and spines in place. (Compare Plate 16, fig. 4.)
 Fig. 2. After Wyville Thomson, 1861, adapted from his Plate 4, fig. 2. Cotype. Enlarged. Impression of the exterior showing four columns of plates in an ambulacral area and associated interambulacral plates.
 Fig. 3. After Wyville Thomson, 1861, Plate 4, fig. 3. Cotype. Much enlarged. A single interambulacral plate with a primary and secondary tubercles and a primary spine.
 Fig. 4. British Museum Coll., E. 1,300. $\times 3.5$. External mold, showing eight columns of plates in an interambulacral area, the width of an ambulacrum, also tubercles and spines.

Koninckocidaris silurica sp. nov.

Page 285.

- Fig. 5. Same specimen as photograph, Plate 19, fig. 1. Holotype. $\times 1.4$. About three ambulacral plates equal the height of an interambulacral. Ambulacral plates bevel over the interambulacral and imbricate dorsally, as this is an internal view. Pores are near the middle of the ambulacral area, a usual character of the interior. Eight columns of nearly rhombic interambulacral plates in area A, all of which extend to the apical disc. All interambulacral plates imbricate ventrally and toward the center, nearly covering column 7. This is because it is an internal view. (Compare text-figs. 32-37, p. 75.) An ocular plate is in place capping ambulacrum B and the lateral borders of interambulacra A and C. Two genitals are in place, partially restored in C, as indicated by dotted lines, and a few periproctal plates. A plate between ocular B and genital A may be a displaced periproctal plate. The apical disc is small.
 Fig. 6. Same specimen, ambulacral plates of area J. $\times 3.6$. An elevated T-shaped ridge is on each plate with pores on the ventral side of the same. An X in figs. 5 and 6 indicates the location of the plates figured in each.

Lepidocentrus rhenanus (Beyrich).

Page 288.

- Fig. 7. Devonian, Wippenfurth. Museum für Naturkunde Coll., Berlin. Holotype. $\times 0.9$. The specimen is an internal mold. Ambulacral plates low, interambulacra with five columns in each area. In area E, the primordial interambulacral plate is in the basicoronal row; there are two plates in the second row, three in the third, and four in the fourth row, the fifth column coming in below the ambitus. Jaws present.

Lepidocentrus mülleri Schultze.

Page 289.

- Fig. 8. Same specimen as photograph, Plate 19, fig. 2. Holotype. $\times 0.9$. Ambulacra narrow, plates low. Interambulacrum A with 11 columns of plates imbricating strongly dorsally and from the center laterally; several of the columns drop out, passing dorsally.
 Fig. 9. Same specimen from the area marked X in fig. 8. $\times 3.6$. Ambulacral plates showing the number against an interambulacral plate, the lateral position of pores and the beveling under interambulacral plates on the left.
 Fig. 10. Same specimen, from the reverse side. $\times 3.6$. Internal impression from near mid-zone. Pores in the center of each plate, ambulacral plates wider than on exterior, and interambulacral more angular than on exterior.
 Fig. 11. Middle Devonian, Pelm, Prussia. Mus. Comp. Zool. Coll., 3,103 (from R. T. J. Coll.). $\times 1.7$. Interambulacral plate from a left half-area, showing beveling, two primary tubercles with scrobicules and secondary tubercles.
 Fig. 12. Same horizon, locality, and collection. $\times 1.7$. Plate from a right half-area with one primary tubercle, the more usual character.
 Fig. 13. Middle Devonian, Muhlenberg, near Gerolstein, Prussia (after Schultze, 1866, Plate 13, fig. 1b). Enlarged. Ambulacra narrow, plates low, pore-pairs uniserial and near the interambulacral suture.

Lepidocentrus eifelianus Müller.

Page 291.

- Fig. 14. Devonian, Rommersheim, Prussia (after Müller, 1857, Plate 3, fig. 1). Cotypes. $\times 0.9$. Interambulacral plates showing surface characters and beveling.

Tornquistellus gracilis (Tornquist).

Page 291.

- Fig. 15. Lower Carboniferous, Hunsrück, Prussia (after Tornquist, 1897, Plate 20, fig. 5). Holotype. $\times 0.9$ and enlarged. Tubercles widely spaced, small primaries with scrobicular rings.

Fig. 7 from my sketch; figs. 13, 15 copied by W. M. Barrows; all others drawn by J. Henry Blake.

PLATE 21.

Lepidocentrus drydenensis (Vanuxem).

Page 288.

- Fig. 1. Same specimen as photograph, Plate 16, fig. 5. Holotype. $\times 0.9$. Internal mold with the superposed combination of some external characters. Ventral view, ambulaera are narrow, plates low. Interambulacral areas with apparently nine columns of plates which are ill defined as indicated by dotted lines, for the impression is weak. Acicular spines in place and also in the adjacent matrix, peristomal area small.
- Fig. 2. Same specimen. $\times 3.6$. Ambulacral plates with pores, from area D of fig. 1.
- Fig. 3. Same specimen. $\times 3.6$. Ambulacral plates from area B, showing the number apposed to an adradial plate. An X in figs. 1, 2, 3 indicates the location of the enlarged figures.

Lepidocentrus whitfieldi sp. nov.

Page 290.

- Fig. 4. Same specimen as photographs, Plate 19, figs. 6, 7. Holotype. $\times 1.8$. Ventral view, internal mold. Ambulaera narrow, plates low. Eleven columns of interambulacral plates in an area. A primordial interambulacral plate is in place in the basicoronal row.
- Fig. 5. Same specimen. $\times 1.8$. Dorsal view, genital plates have numerous pores, ocular plates restored as indicated by dotted lines. The apical disc though incomplete is evidently small proportionately to the diameter of the test. This is the only specimen known in the genus *Lepidocentrus* which shows the plates of the apical disc (p. 287).

Hyattechinus rarispinus (Hall).

Page 292.

- Fig. 6. Waverly Group, Lower Carboniferous, Meadville, Pennsylvania. Amer. Mus. Nat. Hist. Coll., 6,392. Holotype. $\times 1.8$. External sandstone mold of the dorsal side, so that the lettering is reversed. Ambulaera are narrow, plates low, eleven columns of interambulacral plates in each area, the eleventh introduced above the ambitus, columns 1 and 2 drop out dorsally. Same specimen as photograph, Plate 22, fig. 7. (See pp. 294, 395.)

PLATE 22.

Hyattechinus rarispinus (Hall).

Page 292.

Figs. 1-6, 8. Waverly Group, Lower Carboniferous, Warren, Pennsylvania; collected by the late Professor C. E. Beecher, and now in Yale University Museum.

- Fig. 1. Yale Mus. Coll., 332. Natural size. External mold of the ventral side, and in areas B, C, and D in part an internal mold of the dorsal side. Ambulacra petaloid ventrally and narrow dorsally; the interambulacra all show a primordial interambulacral plate in the basicoronal row and a rapid introduction of succeeding columns of plates. Ambulacral plates only on the peristome. Tubercles are seen on the ventral portion, as that is an external mold; no tubercles on the portion that is dorsal, as that is an internal mold (pp. 21, 22). Drawing, Plate 23, fig. 1.
- Fig. 2. Yale Mus. Coll., 333. Counterpart of the same specimen as fig. 1. Internal mold of the ventral side, and in areas A, B, C, and D in part, an external mold of the dorsal side. An impress of the lantern fills the oral area. Drawings, Plate 23, figs. 2, 7.
- Fig. 3. Yale Mus. Coll., 329. Natural size. External mold of the ventral side, showing broad petaloid ambulacra, interambulacra with tubercles, and in places spines impressed in the mold. The peristome is covered with ambulacral plates only.
- Fig. 4. Yale Mus. Coll., 328. Counterpart of the same specimen as fig. 3. External mold of the dorsal side. Ambulacra narrow, interambulacra with tubercles and a general impression of the dorsal face of the lantern, caused by the flattening of the test.
- Fig. 5. On the same slab as fig. 3. Yale Mus. Coll., 329. External mold of the ventral side, showing in part structures as in fig. 3. Drawing, Plate 23, fig. 6.
- Fig. 6. Counterpart of same specimen as fig. 5. Yale Mus. Coll., 328. External mold of the dorsal side, showing in part structures as in fig. 4.
- Fig. 7. Waverly Group, Lower Carboniferous, Meadville, Pennsylvania. Amer. Mus. Nat. Hist. Coll., 6,392. Holotype. Natural size. External sandstone mold of the dorsal side. Ambulacra narrow, plates low, eleven columns of plates in each interambulacral area (pp. 294, 395). Drawing, Plate 21, fig. 6.
- Fig. 8. Yale Mus. Coll., 325. Natural size. External mold of the dorsal side. Ambulacral areas narrow, interambulacra with 11 columns of plates in areas A and G, 12 columns of plates in area I, or 13 columns of plates in areas C and E; tubercles prominent; a general impression exists of the top of lantern, caused by the flattening of the test. Drawing, Plate 23, figs. 3, 4. On the reverse side of this slab are more or less complete impressions of seven other specimens of the same species, showing that it was common in the locality.

PLATE 23.

Hyattechinus rarispinus (Hall).

Page 292.

Figs. 1-7. Waverly Group, Lower Carboniferous, Warren, Pennsylvania, collected by the late Professor C. E. Beecher; all are in Yale University Museum.

- Fig. 1. Yale Mus. Coll., 332. $\times 1.9$. Same specimen as photograph, Plate 22, fig. 1. External mold of the ventral side and in areas B, C, and D in part, an internal mold of the dorsal side. Ambulacra broad, petaloid ventrally, pore-pairs uniserial. Interambulacra very clear; the primordial interambulacral plates are in the basicoronal row, two plates in the second row, three in the third, four plates in the fourth row, and so on, the columns coming in very rapidly, showing a highly accelerated development. The peristome is covered with many rows of low ambulacral plates only (pp. 81, 213). In areas B, C, and D there exists in part an internal mold of the dorsal side; these plates therefore have no tubercles. The ambulacral plates here are lower than they are ventrally and the areas are markedly narrower.
- Fig. 2. Yale Mus. Coll. 333. Same specimen as photograph, Plate 22, fig. 2. $\times 2.7$. Internal mold of the ventral side. Ambulacral plates show pore-pairs as elevated plugs, also pits near the median line, which are molds of spinose elevations extending proximally from the ambulacral plates. (Compare Plate 3, figs. 12, 13; p. 61.) Primordial interambulacral plates are in the basicoronal row. In the center the mold of the lantern represents interradially casts of the five alveolar cavities (each of which was enclosed by two half-pyramids); radially, casts of the spaces between the half-pyramids, which in life were occupied by the interpyramidal muscles (compare Plate 5, fig. 2). The lantern itself is quite absent.
- Fig. 3. Yale Mus. Coll., 325. $\times 1.6$. Same specimen as photograph, Plate 22, fig. 8. External mold of the dorsal side. Ambulacra are narrow, plates low. Interambulacral areas with 11 columns of plates in areas A and G, 12 columns of plates in area I, and in two areas, C and E, 13 columns of plates (p. 50); part of the columns, notably 1 and 2, drop out dorsally as a senescent character. Primary and secondary tubercles exist as sunken impressions.
- Fig. 4. Same specimen. Yale Mus. Coll., 325. $\times 3.7$. Ambulacral detail enlarged; from the point marked X in fig. 3. Pore-pairs are in peripodia.
- Fig. 5. Yale Mus. Coll., 327. External mold of a fragment of the dorsal side. $\times 5$. Primary and secondary tubercles on interambulacral plates.
- Fig. 6. Yale Mus. Coll., 329. Same specimen as Plate 22, fig. 5. $\times 5$. External mold of the ventral side with spines in place.
- Fig. 7. Yale Mus. Coll., 333. $\times 2$. Same specimen as photograph, Plate 22, fig. 2. $\times 1.9$. Internal mold of the ventral side, showing pore-pairs existent as plugs, also pits which represent elevated spine-like processes on the proximal face of the ambulacral plates. (Compare Plate 3, figs. 12, 13; Plate 24, fig. 6; p. 61.)

As the figures on this plate are all from drawings of external or internal sandstone molds, the orientation and lettering are reversed from what they would be if taken from external or internal views of a test (pp. 20, 22).

PLATE 24.

Hyattechinus pentagonus sp. nov.

Page 295.

Figs. 1-4. Waverly Group, Lower Carboniferous, Meadville, Pennsylvania.

- Fig. 1. Alleghany College Coll. Holotype. Natural size. External mold of the dorsal side. The test is strongly pentagonal in outline; ambulacra are narrow, interambulacra broad, each with 14 columns of plates in each area, genital and ocular plates in place. The apical disc is small, being proportionately about 16% of the diameter of the test. Drawings, Plate 25, figs. 3, 4.
- Figs. 2, 3. Similar external molds of the dorsal side of two other specimens of the same species and on the same slab. Paratypes.
- Fig. 4. Mus. Comp. Zool. Coll., 3,107 (from R. T. J. Coll.). Paratype. Natural size. External mold of the ventral side. Ambulacra broad, petaloid. Primordial interambulacral plates in the basicoronal row; additional columns of plates come in with a very accelerated development. Drawing, Plate 25, fig. 1.

Hyattechinus beecheri sp. nov.

Page 297.

- Figs. 5-8. Waverly Group, Lower Carboniferous, Warren, Pennsylvania. Obtained by the late Professor C. E. Beecher from the late Dr. Randall, who collected it; now in Yale Univ. Mus. Coll., 323. Holotype. Natural size. Bilaterally symmetrical through an ambulacrum and opposite interambulacrum, which I consider as the axis III, 5, a unique character in regular Echini (p. 32). The specimen is an internal mold representing an impress of the inner side of the plates, but so nearly perfect, that it is represented spread out in Plate 26.
- Fig. 5. Ventral view. Natural size. Ambulacra broad, petaloid, ambulacral pores represented by elevated plugs. In addition, each plate ventrally bears a reentrant elongate pit which represents the impression of an elevated spine-like process on the inner face of the plates, seen best in areas III and IV. Primordial interambulacral plates are in the basicoronal row and additional interambulacral columns come in rapidly, the full number being attained at or just above the ambitus.
- Fig. 6. Drawn from a wax cast of the ventral side which therefore represents the internal face of the ventral plates. $\times 3.7$. The pore-pairs exist as pits and the spine-like elevated processes stand up as ridges; from the area indicated by X in Plate 26. (Compare Plate 3, figs. 12, 13; p. 61.)
- Fig. 7. Side view, in profile. Natural size. The test is apparently of the original form and height.
- Fig. 8. Dorsal view. Natural size. Ambulacra narrow, plates low, the impressions of the genital and some periproctal plates are in place. The apical disc is small proportionately to the length of the test. This specimen is shown spread out in Plate 26, and the apical portion is shown in Plate 25, fig. 5.

Figs. 1-3 photographed by H. W. Tupper; other photographs by F. A. Saunderson; the drawing, fig. 6, by J. Henry Blake.

PLATE 25.

Hyattechinus pentagonus sp. nov.

Page 295.

Figs. 1-4. Waverly Group, Lower Carboniferous, Meadville, Pennsylvania; all external sandstone molds.

- Fig. 1. Mus. Comp. Zool. Coll., 3,107 (from R. T. J. Coll.). Paratype. $\times 1.8$. External mold of the ventral side, the same specimen as photograph, Plate 24, fig. 4. Ambulacra broad, petaloid; pore-pairs uniserial with clearly defined peripodia. Interambulacra in each area have the primordial plate in the basicoronal row; there are two plates in the second row and three plates in the third row, dorsal to which new columns are added with great rapidity, indicating a very accelerated development, eleven columns being attained before reaching the ambitus. The peristome, as far as preserved, has ambulacral plates only. The plates are partially restored in areas D and E, as indicated by dotted lines.
- Fig. 2. Same specimen. $\times 7$. Enlarged to show detail of ambulacral plates. Pore-pairs in peripodia from the area marked X in fig. 1.
- Fig. 3. Alleghany College Coll. Holotype. $\times 1.8$. Dorsal view. Same specimen as photograph, Plate 24, fig. 1. Ambulacra narrow, marking the limits of the pentagon radially. Interambulacra with 14 columns of plates in each area, the highest number known in any sea-urchin. The 13th and 14th columns originate above the ambitus. In area C there are only four plates in column 14. Columns 1 and 2 and some additional columns drop out before reaching the apical disc. Four of the genital and ocular plates and a few periproctal plates are in place dorsally. The apical disc is small, measuring proportionately about 16 % of the diameter of the test. Remarkably clear for a sandstone mold.
- Fig. 4. Same specimen. Holotype. $\times 3.6$. Enlargement to show the dorsal structure of one interambulacrum. Columns 1, 2, 10, and 13 drop out before reaching apical disc.

Hyattechinus beecheri sp. nov.

Page 297.

- Fig. 5. Yale Mus. Coll., 323. Same specimen as photograph, Plate 24, fig. 8 and Plate 26, fig. 1. Holotype. $\times 3.6$. Shows genital, ocular, and periproctal plates. The oculars and in part the genital and periproctal plates are restored, as indicated by dotted lines. All of these plates are represented by impressions only as the specimen is an internal sandstone mold. The genital pores are not indicated as they were not seen in the specimen.

Figs. 3 and 4 drawn by J. H. Emerton; figs. 1, 2, 5 by J. Henry Blake.

PLATE 26.

Hyattechinus beecheri sp. nov.

Page 297.

Fig 1. Yale Mus. Coll., 323, holotype. Same specimen as photographs, Plate 24, figs. 5, 7, 8, and Plate 25, fig. 5. $\times 1.1$.

This unique specimen, though a sandstone mold of the interior, bears the impress of plates so that it can be drawn spread out by the Lovén method with very few gaps, part of which are filled in as plates with dotted lines in areas 3, 4, and 5. The gaps of the interambulacra laterally at the ambitus are due to the mechanical requirements in making the drawing. This is the only regular sea-urchin known that is bilaterally symmetrical through an ambulacrum and posterior interambulacrum, and the orientation is based on this bilateral symmetry.

Ambulacra broad, petaloid ventrally, narrow dorsally. Ambulacral plates ventrally near the median suture have a series of pits caused by elevated spinose processes on the proximal face of the plates (Plate 24, fig. 6; compare Plate 3, figs. 12, 13; p. 61). Interambulacra have each 11 columns of plates. The primordial interambulacral plates are in the basicoronal row in each area; there are two plates in the second row, three in the third, and four in the fourth row, each indicating the introduction of a newly added column. Column 5 originates in the fifth row in areas 1, 5, and 4, but not until the sixth row in areas 2 and 3. The sixth column originates in the sixth row in areas 1, 5, and 4, but not until the eighth row in areas 2 and 3. This seems to accord with the bilateral symmetry, the posterior interambulacral trivium developing more quickly than the anterior interambulacral bivium. After the sixth, the succeeding columns come in with great rapidity, practically a new column being added in each row of each area until the full number is attained at or near the ambitus. Dorsally, columns 1 and 2 and some additional columns in each area drop out before reaching the apical disc. The peristome as far as indicated is covered with ambulacral plates only, and the lantern is represented by casts of the alveolar cavities and inner faces of the teeth.

PLATE 27.

Pholidechinus brauni sp. nov.

Page 299.

Figs. 1-6. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana.

- Fig. 1. Mus. Comp. Zool. Coll., 3,109, (from R. T. J. Coll.) holotype. Natural size. Ambulacra narrow throughout. Nine columns of plates in both interambulacral areas at the mid-zone, but a tenth column exists dorsally in area C. Tubercles and some spines are clear in both ambulacral and interambulacral areas of this specimen. Drawings, Plate 28, figs. 2, 9.
- Fig. 2. F. Braun Coll., paratype. Natural size. Nine columns of plates in interambulacra A and I. Teeth in place, and ambulacral plates only on the peristome. Drawing, Plate 28, fig. 1.
- Fig. 3. British Mus. Coll., E 10,678 (from R. T. J. Coll.), paratype. Natural size. A tenth column originates in interambulacrum A earlier than in fig. 1. Drawings, Plate 28, figs. 4-6.
- Fig. 4. Yale Mus. Coll., 321, paratype. $\times 3$. This figure with figs. 5, 6, represents the most perfect lantern known in a Palaeozoic echinoid. Teeth in place. Peristome in part in place on the lantern, consisting of low, wide imbricate ambulacral plates only. The pyramids are wide-angled, producing as a consequence a wide and flaring lantern which is largely visible from this ventral view. There are wide outwardly curving spaces for long interpyramidal muscles (compare Plate 2, figs. 19, 20); the outer ends of the epiphyses, braces, and in area D a compass are visible in this view.
- Fig. 5. Same specimen, dorsal view. $\times 3$. Five teeth nearly or quite in place and in line with the pyramidal sutures. In areas B, J, H, and F, narrow epiphyses and braces are in place. In area D, a compass also exists, though slightly displaced; distally it is not bifurcate, probably due to wear.
- Fig. 6. Same specimen, profile view. $\times 3$. The lantern is inclined at an angle of about 45° , foramina magna moderately deep. Teeth visible ventrally and just above the foramina dorsally, narrow epiphyses are in place, capping the half-pyramids; braces are in place between the epiphyses, and the compass is just visible in area D. In area F, a wide space exists between the pyramids for a long interpyramidal muscle. (Compare Plate 2, fig. 19, and text-fig. 207, p. 184.)

Photographs by F. A. Saunderson; drawings of the lantern by J. Henry Blake.

PLATE 28.

Pholidechinus brauni sp. nov.

Page 299.

Figs. 1-9. Keokuk Group, Lower Carboniferous, Crawfordsville, Montgomery County, Indiana.

- Fig. 1. F. Braun Coll. Paratype. $\times 2.1$. Ambulacra narrow throughout, plates laterally meeting the interambulacra or alternate plates in part nearly or quite cut off from interambulaeral contact. Pore-pairs slightly biserial. Interambulacra with nine columns in each area. The primordial interambulaeral plate is in the basicoronal row in area 1, and is restored in area A. Interambulacral plates imbricating strongly dorsally and laterally and rounded upward and toward the ambulaerum on either side, except the median column, which is rounded and imbricates laterally in two directions (compare text-fig. 32, p. 75). Teeth in place, ambulaeral plates only on the peristome. Same specimen as photograph, Plate 27, fig. 2.
- Fig. 2. Mus. Comp. Zoöl. Coll., 3,109 (from R. T. J. Coll.), holotype. $\times 2.1$. Ambulacral plates ventrally are all primaries, meeting the interambulaerum equally. Ten columns of plates in interambulaerum C, the last column originating late. The beveled edges of the plates show clearly below the initial plate of column 8. There are flanges on the outer and dorsal border of each plate, compare fig. 9. Spines and tubercles in place. Same specimen as photograph, Plate 27, fig. 1.
- Fig. 3. Same specimen as fig. 2, showing the details of tubercles and spines from the area marked X, in fig. 2. $\times 8$.
- Fig. 4. British Mus. Coll., E 10,678 (from R. T. J. Coll.), paratype. $\times 2.1$. Ten columns of plates in interambulaerum A and apparently in I, the tenth column originating earlier than in fig. 2. Column 9 in both areas imbricates dorsally and laterally in two directions; columns 7 and 8 in area A drop out passing dorsally. Same specimen as photograph, Plate 27, fig. 3.
- Fig. 5. Same specimen as fig. 4, from the area marked X in that figure, showing alternate plates nearly or quite cut off from the interambulaerum. Pore-pairs in peripodia. $\times 5.4$.
- Fig. 6. Same specimen as fig. 4, from the area marked XX in that figure, showing alternate plates narrowed but not cut off from the interambulaerum. $\times 5.4$.
- Fig. 7. Amer. Mus. Nat. Hist. Coll., $\frac{7,243}{1}$, paratype. $\times 2.5$. In profile to show the lateral beveling; adradial plates are shaded.
- Fig. 8. The same specimen. $\times 2.5$. Shows ambulaeral plates alternately meeting and cut off from interambulaeral contact; biserial pore-pairs and beveling of plates.
- Fig. 9. Same specimen as photograph, Plate 27, fig. 1, and this Plate, fig. 2. Holotype. $\times 3.2$. Plates from near the mid-zone of area A, showing delicate attenuated flanges that exist superficially on the dorsal and both sides of column 9, and on the dorsal and lateral border of the plates of other interambulaeral columns, a unique specific character as far as known.
- Fig. 10. Keokuk Group, Montgomery County, Indiana. Mus. Comp. Zoöl. Coll., 3,111 (from R. T. J. Coll.), paratype. $\times 2.2$. Dorsal portion of a test showing two low, wide genitals each with numerous genital pores,

PLATE 29.

Palaeochinus quadriserialis Wright.

Page 305.

- Fig. 1. Lower Carboniferous Limestone, Rathkeale, County Limerick, Ireland. British Mus. Coll., E 193. Natural size. Test elliptical, ambulacra narrow, four columns of plates in each interambulacral area. Apical disc small. Drawings, Plate 30, figs. 1-4.

Palaeochinus ellipticus M'Coy.

Page 307.

- Fig. 2. Lower Carboniferous, Millicent, Clare, County Kildare, Ireland. Holotype. Natural size. Griffith Collection, Science and Arts Mus. Coll., Dublin. Test elliptical, ambulacra narrow, five columns of plates in each interambulacral area. Drawings, Plate 30, figs. 8-10.

Palaeochinus elegans M'Coy.

Page 308.

- Fig. 3. Lower Carboniferous, Hook Head, Fethard, County Wexford, Ireland. Holotype. Natural size. Griffith Collection, Science and Arts Mus. Coll., Dublin. Test spheroidal, ambulacra narrow, five columns of plates in each interambulacral area, apical disc and periproct well preserved. Apical disc small, being proportionately about 16 % of the diameter of the test. Drawings, Plate 31, figs. 1-4.

- Fig. 4. Another specimen of this species on the same slab.

Perischodorus biserialis M'Coy.

Page 401.

- Fig. 5. On same slab as figs. 3, 4. Cotype. Natural size. Dorsal view; one of M'Coy's two original specimens of this species. Interambulacral plates rounded and imbricating dorsally and from the center of each area laterally and over the ambulacra (pp. 402, 403).

Palaeochinus elegans M'Coy.

Page 308.

- Fig. 6. Same specimen as fig. 3, apical region enlarged. $\times 4$. Oculars imperforate, adorally covering the ambulacra and laterally the interambulacra in part on either side. Though the oculars are imperforate, Baily in his figure of this specimen shows two pores in each ocular plate (pp. 309, 363). Genitals with 3 to 5 pores each, genitals E and G have three pores each, genital C has apparently four pores, and genital A has five pores; a number of periproctal plates are in place. Drawing, Plate 31, fig. 4.

Palaeochinus (?) *minor* sp. nov.

Page 310.

- Fig. 7. Kinderhook Group, Lower Carboniferous, Burlington, Iowa. Chicago Univ. Coll., 9,054, holotype. Natural size. Internal sandstone mold. Ambulacra narrow, six columns of plates in an interambulacral area. Drawing, Plate 31, fig. 6.
- Fig. 8. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. Mus. Comp. Zool. Coll., 3,051, paratype. Natural size. Internal sandstone mold. Six columns of plates in four interambulacral areas, but in one interambulacral area there are only five columns of plates. Impressions of all oculars and genitals in place. Oculars all insert. Apical disc measures 8 mm. in diameter.

Palaeochinus (?) *konigii* M'Coy.

Page 450.

- Fig. 9. Arenaceous shale, Lower Carboniferous, Rahan's Bay, Dunkineely, County Donegal, Ireland. Griffith Collection, Science and Arts Museum, Dublin. Holotype. Natural size. Interambulacral plates only. Drawings, Plate 31, fig. 7.

Fig. 1 photographed at the British Museum; figs. 2, 9, by A. C. Bridle in Dublin; figs. 3-7 by F. A. Saunderson; fig. 8, by H. W. Tupper.

PLATE 30.

Palaeochinus quadriserialis Wright.

Page 305.

- Fig. 1. Same specimen as photograph, Plate 29, fig. 1. $\times 1.5$. Test elliptical, with four columns of plates in each interambulacral area. In the upper part of the figure the plates are present as indicated by spine tubercles; the lower part is represented by an internal mold of the bases of the plates.
- Fig. 2. Same specimen, from the area marked X in fig. 1, showing ambulacral detail. $\times 4.3$.
- Fig. 3. Same specimen spread out by the Lovén method. $\times 1.5$. In the aboral part of the specimen, the plates are present as shown by pores in ambulacral plates and tubercles on interambulacral plates. Parts drawn from the mold of the interior are shown in simple outline; restored portions are indicated by dotted lines (compare Plate 29, fig. 1). Ambulacra narrow, plates all primaries, pore-pairs uniserial. In the basicoronal row of the interambulacra there are two plates in each area, in the second row three plates, and in the third row four plates, excepting in area C, in which the fourth column originates in the fourth row, a rare variation (p. 68). Above this zone no more columns are added. (Compare text-fig. 217, p. 191.)
- Fig. 4. Same specimen, apical disc, restored as indicated by dotted lines. Enlarged $\times$ about 3. Oculars are imperforate, and adorally cover the ambulacra and laterally the interambulacra in part on either side. Genitals with three pores each, and secondary tubercles as on plates of the corona.

Figs. 5-7. Lower Carboniferous, Middleton, County Cork, Ireland (after Wright, 1865, Plate 3, figs. 1a-1c). Holotype.

- Fig. 5. Four columns of plates in each interambulacral area. $\times 0.9$.
- Fig. 6. The same. Ambulacral detail enlarged.
- Fig. 7. The same. A single interambulacral area. $\times 0.9$.

Palaeochinus ellipticus M'Coy.

Page 307.

- Fig. 8. Same specimen as photograph, Plate 29, fig. 2, holotype. Enlarged ventral border of interambulacrum A to show development; two plates in the basicoronal row, three plates in the second, and four in the third row, the fifth column coming in two rows above the fourth.
- Fig. 9. Same specimen, enlarged $\times$ about 1.5. Interambulacrum at the mid-zone with five columns of plates.
- Fig. 10. Same specimen. $\times 3$. Ambulacral detail at the mid-zone, showing two columns of primary plates, pore-pairs uniserial (see p. 308).

Palaeochinus elegans M'Coy.

Page 308.

- Fig. 11. Lower Carboniferous, Hook Point, County Wexford, Ireland. Museum of Practical Geology Coll., London, 6,580. $\times 6$. Ambulacral detail. Same specimen as Plate 31, fig. 5.

Figs. 1 and 11 drawn by G. C. Chubb; figs. 3 and 4 by A. T. Hollick; the other figures are copies of Wright's figures or of my sketches by J. Henry Blake.

PLATE 31.

Palaeechinus elegans M'Coy.

Page 308.

- Fig. 1. Same specimen as photograph, Plate 29, fig. 3. Holotype. $\times 1.8$. Ambulacra narrow, plates all primaries, pore-pairs uniserial. Five columns of plates in an interambulacral area. (Compare text-figs. 9, p. 54; 15, p. 59; 237, p. 231.)
- Fig. 2. Same specimen. $\times 5.4$. Ambulacral detail from the area marked X in fig. 1. Ambulacral plates all primaries, pore pairs uniserial.
- Fig. 3. Same specimen, showing ambulacral plates beveling over the adradials. $\times 1.8$.
- Fig. 4. Same specimen, dorsal area. $\times 3.5$. In area E, column 5 drops out dorsally; oculars shaded, all are imperforate, reaching the periproct and adorally covering the ambulacra and laterally the interambulacra in part on either side. Four genitals nearly or quite in place with three, four, or five pores each; by oversight only three pores are shown in genital A, whereas there should be five pores as seen in the enlarged photographic figure (Plate 29, fig. 6); genital I is wanting. Plates of the periproct are thick and angular.
- Fig. 5. Lower Carboniferous, Hook Point, Wexford, Ireland. Museum of Practical Geology Coll., London, 6,580. $\times 2.7$. Five columns of plates in interambulacrum A and spines in place. For an enlarged ambulacrum of the same specimen, see Plate 30, fig. 11.

Palaeechinus (?) minor sp. nov.

Page 310.

- Fig. 6. Same specimen as photograph, Plate 29, fig. 7. Holotype. $\times 2.7$. Internal mold. Ambulacra narrow; all plates (at least in this internal view) primaries with pore-pairs uniserial. The lower part of the figure drawn from area I, is restored ventrally as indicated by dotted lines, and shows the introduction of columns 4, 5, and 6. The upper part of the figure is drawn from area E. The sixth and third columns drop out dorsally. The apical disc is small, oculars are all insert, genitals each with three pores.

Palaeechinus (?) konigii M'Coy.

Page 450.

- Fig. 7. Same specimen as photograph Plate 29, fig. 9 (after M'Coy, 1844, Plate 24, figs. 1a, 1b). Holotype. $\times 0.9$ and enlarged. Interambulacral plate, such being all that is known of the species.

Fig. 5 drawn by G. C. Chubb; figs. 1-4 from my sketches; fig. 6 from nature; and fig. 7 from M'Coy by J. Henry Blake.

PLATE 32.

Maccoya burlingtonensis (Meek and Worthen).

Page 312.

Figs. 1-3. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa.

- Fig. 1. F. Springer Coll., 8,003. Natural size. Ventral view. Ambulacral plates ventrally are all primaries, pore-pairs uniserial. At the mid-zone plates are alternately primaries and occluded, pore-pairs biserial. Interambulacrum in the basicoronal row with two plates, in the second row three plates, and in the third row four plates. Drawing, Plate 33, fig. 1.
- Fig. 2. E. Kirk Coll. Natural size. Median and dorsal area. Ambulacral plates at the mid-zone are alternately primaries and occluded; pore-pairs biserial, dorsally in the placogenous zone; the ambulacral plates are all primaries and pore-pairs are uniserial. Four columns of plates in interambulacral area A. Tubercles alike on all plates, ambulacral and interambulacral. Drawing, Plate 33, fig. 2.
- Fig. 3. F. Springer Coll., 8,002. Natural size. Dorsal half of test. Four columns of plates in each interambulacrum.

Maccoya sphaerica (M'Coy).

Page 317.

- Fig. 4. Lower Carboniferous, Waterford, County Wexford, Ireland. British Mus. Coll., E 361. Natural size. Ambulacra narrow, pore-pairs biserial at the mid-zone. Five columns of plates in each interambulacral area. Oculars all insert, periproct exceptionally perfect (p. 319). Drawings, Plate 34, figs. 4-6.
- Fig. 5. Lower Carboniferous, probably County Kildare, Ireland. Trinity College Coll., Dublin. Holotype. Natural size. Ambulacra narrow, six or seven columns of plates in each of the several interambulacral areas (p. 318). Drawing, Plate 34, fig. 7.

Pholidechinus brauni sp. nov.

Page 299.

- Fig. 6. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana. F. Springer Coll., 8,019, paratype. Natural size. An internal mold, with nine columns of plates in interambulacral area A, the median column is very narrow. (Compare similar view of *Koninekocidaris*, Plate 20, fig. 5.)

Palaeochinus (?) **minor** sp. nov.

Page 310.

- Fig. 7. Base of Burlington Limestone, Lower Carboniferous, Burlington, Iowa. E. Kirk Coll. Paratype. Natural size. Six columns of plates in each of the five interambulacral areas.

Figs. 1-3, 6, 7 from photographs by F. A. Saunderson; fig. 4 taken in the British Museum; fig. 5 taken in Dublin by A. C. Bridle.

PLATE 33.

Maccoya burlingtonensis (Meek and Worthen).

Page 312.

Figs. 1-5. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa.

- Fig. 1. Same specimen as photograph, Plate 32, fig. 1. $\times 2.6$. Ventral view. Ambulacral plates ventrally are all primaries, with pore-pairs uniserial; at the mid-zone ambulacral plates are alternately primaries and nearly or quite occluded, with pore-pairs biserial (p. 55). Interambulacrum with two plates in the basicoronal row, three plates in the second row, and four plates in the third row. (Compare text-figs. 16, p. 59; 237, p. 231.)
- Fig. 2. Same specimen as photograph, Plate 32, fig. 2. $\times 2.7$. Ambulacral plates at the mid-zone, alternating primaries and occluded, with pore-pairs biserial; at the dorsal portion representing the placogenous zone, ambulacral plates are all primaries and pore-pairs are uniserial as in the youthful plates ventrally (fig. 1). Four columns of interambulacral plates in area A. (Compare text-figs. 10, p. 54; 237, p. 231.)
- Fig. 3. After Meek and Worthen, 1866, Plate 16, fig. 3a. Holotype. $\times 0.9$. Four columns of plates in an interambulacral area.
- Fig. 4. Mus. Comp. Zool. Coll., 3,049. External view. $\times 3.5$. Ambulacral plates are alternately primaries and occluded, with pore-pairs biserial.
- Fig. 5. The same individual plates as fig. 4. Internal view. $\times 3.5$. All ambulacral plates are primaries and pore-pairs are uniserial, also the adambulacral plate is rounded on the adradial suture which it is not on the exterior (p. 60). (Compare figs. 4 and 5 with Plate 34, figs. 2, 3.)

Maccoya intermedia (Keeping).

Page 314.

- Fig. 6. Lower Carboniferous, Hook Head, County Wexford, Ireland. Palaeontological Museum, Munich. $\times 1.8$. Dorsal portion of a test. Ambulacral plates are alternately primaries and occluded, with pore-pairs biserial. Four columns of interambulacral plates in area A, numerous secondary tubercles.
- Fig. 7. Same specimen. $\times 3.6$. Ambulacral detail and tubercles.
- Fig. 8. Same specimen. $\times 3.5$. Viewed from the interior. In this view, ambulacral plates all cross the half-areas, pore-pairs are uniserial, and are farther from the interambulacral suture than on the exterior. (Compare Plate 34, figs. 2, 3.)
- Fig. 9. The same specimen and view as fig. 8. $\times 6$. Ambulacral plates more enlarged.
- Fig. 10. Carboniferous, Hook Head, County Wexford, Ireland (after Keeping, 1876, Plate 3, fig. 2). Sedgwick Museum, Cambridge, England. Holotype. $\times 1.3$. For structural details of this specimen see Plate 34, figs. 2, 3.
- Fig. 11. Lower Carboniferous, Hook Head, Wexford, Ireland. Sedgwick Museum Coll., Cambridge, England, 6. Enlarged. Four columns of plates in each interambulacral area; ocular F is exsert, all other oculars are insert.
- Fig. 12. Same horizon and locality, Sedgwick Museum, Cambridge, England. Enlarged. Genitals are in contact shutting out all the oculars from the periproct, a very unusual character in the Palaeozoic (p. 89). Three or five pores in each genital plate.

Maccoya phillipsiae (Forbes).

Page 316.

- Figs. 13, 14. Caradoc conglomerate, Silurian [?], under Worcester Beacon, England (after Forbes, 1848, Plate 29, figs. 1, 1a. Holotype.
- Fig. 13. View of the specimen which is evidently poorly preserved. $\times 0.9$.
- Fig. 14. Enlarged and partially restored. Ambulacral plates are alternately primaries and narrow occluded plates. Five (?) columns of plates in an interambulacral area.

Figs. 1, 2, 4, 5 drawn from nature, and 11, 12 from my sketches by J. Henry Blake; figs. 3, 10, 13, 14 copied by W. M. Barrows; figs. 6-9 drawn by Anton Birkmaier.

PLATE 34.

Maccoya intermedia (Keeping).

Page 314.

- Fig. 1. Lower Carboniferous, Hook Head, County Wexford, Ireland. Palaeontological Museum, Munich. $\times 1.2$. Four columns of plates in two interambulacral areas. The only ocular preserved is insert.
- Fig. 2. Lower Carboniferous, Hook Head, County Wexford, Ireland. Sedgwick Museum Coll., Cambridge, England. Holotype. $\times$ about 4.6. On account of the separation of plates on the adradial suture, the structure is very clear. Ambulacral plates are alternately primaries and ocluded, pore-pairs biserial. Interambulacral plates bevel under ambulacrals on the adradial suture, so that here the adradial plates present an inclined face. On the outer border of this face there are impressions of the primary plates only; but on the inner, or proximal border of the inclined face, there are impressions of each ambulacral plate, as on the interior all ambulacral plates cross the half-areas, as shown in fig. 3 (p. 60).
- Fig. 3. Same specimen. $\times$ about 4. Seen from the interior, all ambulacral plates cross the half-area, and pore-pairs are uniserial, instead of the plates being alternately primary and ocluded, with pore-pairs biserial, as occurs on the outer face of the same plates.

Maccoya sphaerica (M'Coy).

Page 317.

- Fig. 4. Same specimen as photograph, Plate 32, fig. 4. $\times 1.2$. Ambulacral plates are somewhat schematic, and are more correctly given in figs. 5 and 6 (p. 319). Pore-pairs are biserial at the mid-zone, five columns of plates in each interambulacral area. Oculars are all insert, and adorally cover the ambulacra and laterally the interambulacra in part on either side; periproctal plates in place.
- Fig. 5. Same specimen. $\times 2.6$. From the mid-zone, alternate ambulacral plates marginally narrowed and nearly excluded from interambulacral contact; pore-pairs biserial (p. 319).
- Fig. 6. Same specimen. $\times 2.4$. Dorsal portion enlarged. Ambulacral plates dorsally are all primaries and pore-pairs are uniserial. Oculars all insert and cover the ambulacra and laterally the interambulacra in part on either side; against the oculars young interambulacral plates are existent. Plates of the periproct are thick and angular, the most nearly complete of any periproct known in the family (p. 320). In detail the plates were drawn with great care and are more correct than in fig. 4.
- Fig. 7. Same specimen as photograph, Plate 32, fig. 5. Holotype. $\times 3.5$. Ambulacral detail from area marked X in the photograph. Ambulacral plates are alternately primaries and ocluded, pore-pairs biserial. In the specimen the ambulacral sutures are difficult to see at most parts (p. 317).
- Fig. 8. Lower Carboniferous, Whatley, near Frome, Somerset, England. University Museum Coll., Strassburg. Enlarged. Alternate ambulacral plates are narrowed and nearly excluded from interambulacral contact; pore-pairs biserial (p. 320).
- Fig. 9. Same specimen, enlarged; plates seen from the interior. All pass directly across the half-area and pore-pairs are uniserial.
- Fig. 10. Same specimen. $\times 4.5$. From the dorsal area, where plates are all primaries and pore-pairs are uniserial.

Maccoya gracilis (Meek and Worthen).

Page 323.

- Fig. 11. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. Mas. Comp. Zool. Coll. 3,052, holotype. $\times 2$. Ambulacral plates are alternately primaries, and ocluded; seven columns of interambulacral plates in area A; the seventh column is interrupted dorsally by one row of six plates, above which it reappears with a pentagonal plate next to the heptagonal plate, H. Same specimen as photograph, enlarged, Plate 35, fig. 1.
- Fig. 12. Same specimen as photographs, Plate 35, figs. 2 and 3 (after Jackson; 1896, Plate 7, fig. 36). External sandstone mold. $\times 2$. Ambulacral detail obscure, restored as indicated by dotted lines in area I, and probably incorrectly (p. 324, compare fig. 11). There are seven columns of plates at the mid-zone as far as shown in each interambulacral area; farther dorsally an eighth column is introduced in each area, and a ninth column, consisting of two or three plates, occurs dorsally in area C.

Fig. 1 drawn by Anton Birkmaier; figs. 2, 3 and 5-10 from my sketches by J. Henry Blake; fig. 4 by G. C. Chubb; fig. 11 from nature by J. Henry Blake; fig. 12 drawn by J. H. Emerton.

A. BIRKMAIER, J. HENRY BLAKE, J. H. EMERTON ET G. C. CHUBB DEL.

HELIOTYPE CO. BOSTON

PLATE 35.

Maccoya gracilis (Meek and Worthen).

Page 323.

- Fig. 1. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. Mus. Comp. Zool. Coll., 3,052, holotype. $\times 2$. Ambulacral plates alternately primary and occluded; seven columns of interambulacral plates in area A. Drawing, Plate 34, fig. 11.
- Fig. 2. Waverly Group, Lower Carboniferous, Menifee County, Kentucky. Mus. Comp. Zool. Coll., 3,062. Natural size. An external sandstone mold. Drawing, Plate 34, fig. 12.
- Fig. 3. Same specimen. $\times 2$. Seven columns of interambulacral plates at the mid-zone, eight dorsally in each area and nine columns near the apical disc in area C. Apical disc small. Fig. 2 was lighted from the left and the specimen looks hollow as it is; on the contrary, fig. 3 was lighted from the right and looks in relief, which it is not. The outline of the interambulacral plates and even spine tubercles is very clear for a sandstone mold. As it is an external mold, the orientation is reversed.

Lovenechinus lacazei (Julien).

Page 326.

- Fig. 4. Lower Carboniferous, Armagh, Ireland. British Mus. Coll., E 10,051. Natural size. Four columns of plates in three interambulacral areas; exsert oculars and genitals in place (p. 328). Drawing, Plate 36, fig. 6.
- Fig. 5. Same horizon and locality, British Mus. Coll., E 10,052. Natural size. Shows general spheroidal form and four columns of plates in two interambulacral areas (p. 328). Drawings, Plate 36, figs. 4, 5.
- Fig. 6. Lower Carboniferous Limestone, Llysfaen, near Llandulas, Wales. British Mus. Coll., E 3,432. Natural size. Four columns of massive interambulacral plates in area A (p. 329). Drawings, Plate 36, figs. 7, 8.
- Fig. 7. Lower Carboniferous Limestone, Kirkby Stephen, Westmoreland, England. Yorkshire Philosophical Soc. Coll. Enlarged $\times$ about 1.6. This photograph was taken for me through Dr. F. A. Bather's kindness. Four columns of plates in each ambulacral area and four columns of plates in each interambulacral area, genitals and small exsert oculars in place. This specimen is of much importance as the original described by de Koninck (1869, 1870) as "*Palaechinus sphaericus*," from which species, however, it differs radically in structure, as shown by the drawings and by Dr. Bather's description (pp. 330-334). Drawings, text-figs. 240-243, p. 331.

Fig. 1 from photograph by H. W. Tupper; figs. 2, 3 by F. A. Saunderson; figs. 4-6 taken at the British Museum; fig. 7 by H. Herring at the British Museum.

PLATE 36.

Lovenechinus lacazei (Julien).

Page 326.

- Fig. 1. Lower Carboniferous, Helsington Barrows, southwest of Kendare. Museum of Practical Geology Coll., London, 16,301. $\times 1.7$. Ambulacral plates at the mid-zone demi- and ocluded, pore-pairs biserial; ventrally in area B, all plates are primaries and pore-pairs uniserial for a short distance. In interambulacrum A, plates of columns 1, 2 and 3 are in place, but plates of column 3 partially and column 4 wholly are restored as indicated by dotted lines. In the specimen spaces for these plates exist although the plates are wanting (pp. 328-329). Professor Duncan (1889, p. 200, text-fig. viii) described the ambulacral detail of this specimen as that of "*Palaeochinus ellipticus*," thereby making much confusion. (Compare the type of that species, Plate 29, fig. 2; Plate 30, fig. 10; p. 308.)
- Fig. 2. Same specimen, showing primary ambulacral plates ventrally and the passage to demi- and ocluded plates higher up, from the area marked X in fig. 1. $\times 7$.
- Fig. 3. Same specimen. $\times 7$. Typical ambulacral plates of a half-area at the mid-zone, from the area marked XX in fig. 1.
- Fig. 4. Same specimen as photograph, Plate 35, fig. 5. $\times 1.7$. Four columns of plates in two interambulacral areas, in area A the four columns are seen only dorsally. The single genital plate preserved has three pores (p. 328).
- Fig. 5. Same specimen. $\times 7$. Detail of ambulacrum at the mid-zone, plates are narrow demi- and wide ocluded in each half-area.
- Fig. 6. Same specimen as photograph, Plate 35, fig. 4. $\times 1.7$. Four columns of plates in three interambulacral areas. Three oculars in place, all of which are exsert (p. 328).
- Fig. 7. Same specimen as photograph, Plate 35, fig. 6. $\times 1.3$. Ambulacral plates demi- and ocluded, four columns of massive interambulacral plates in area A, a genital with three pores in place (p. 329).
- Fig. 8. Same specimen. $\times 3.5$. Ambulacral detail of a half-area from the mid-zone, with wide ocluded and narrow demi-plates in a half-area (p. 329).

Figs. 1-3 drawn by A. T. Hollick; all others by G. C. Chubb.

PLATE 37.

Lovenechinus nobilis (Meek and Worthen).

Page 335.

- Fig. 1. Burlington Group, Lower Carboniferous, Webb City, Missouri. Mus. Comp. Zool. Coll., 3,124 (from R. T. J. Coll.). Natural size. Five columns of thick, massive plates in each interambulaeral area. The thickness of the plates is seen well in the lower part of the figure, where also is seen a mold of the internal faeces of some plates that are absent. Drawings, Plate 38, figs. 8, 9.
- Fig. 2. Same horizon and locality. Mus. Comp. Zool. Coll., 3,123 (from R. T. J. Coll.). Natural size. Fragment of a massive specimen, with one interambulaerum complete at the mid-zone and a more complete ambulacrum. Drawings, Plate 38, figs. 4, 5.
- Fig. 3. Burlington Group, Lower Carboniferous, Calhoun County, Illinois. U. S. Nat. Mus. Coll., 33,277. Natural size. This magnificent specimen shows ambulaeral detail clearly in area B, and five columns of plates in each interambulaerum. Drawings, Plate 38, figs. 6, 7.

PLATE 38.

Lovenechinus lacazei (Julien).

Page 326.

Figs. 1-3. Lower Carboniferous, Hunsrück, Prussia (after Tornquist, 1897, Plate 20, figs. 2-4).

- Fig. 1. Showing four columns of plates in an interambulacral area (p. 328).
 Fig. 2. Enlargement of ventral ambulacral plates of the same, plates are all primaries, pore-pairs in peripodia.
 Fig. 3. Enlargement of ambulacral plates from the upper end of the corona, plates are occluded and demi-plates in each half-area, pore-pairs biserial.

Lovenechinus nobilis (Meek and Worthen).

Page 335.

- Fig. 4. Same specimen as photograph, Plate 37, fig. 2. $\times 0.9$. Ambulacral plates are demi- and occluded, five columns of plates in an interambulacral area; tubercles are small secondaries only. The outline of ambulacrum J and the outlines of plates in the lower part of interambulacra A and C are drawn from the mold of their internal faces.
 Fig. 5. Same specimen. $\times 2.7$. Ambulacral detail and tubercles of plates from near the mid-zone as indicated by the plate marked X in both figures.
 Fig. 6. Same specimen as photograph, Plate 37, fig. 3. $\times 3.5$. Ambulacral detail of a half-area from near the mid-zone. In four plates in this figure the inner tongue of the demi-plates is superficially separated from the outer portion of the plates by the widening and confluence of the outer portion of the occluded plates.
 Fig. 7. Same specimen. $\times 3.5$. Ambulacral detail from the same area near the apical disc. In the right half-area there is one demi-plate, but other plates are all primaries and pore-pairs are uniserial.
 Fig. 8. Same specimen as photograph, Plate 37, fig. 1. $\times 0.9$. Five columns of interambulacral plates in two areas. The plates are very massive and thick.
 Fig. 9. Same specimen. $\times 0.9$. Section, partially schematic, showing the curvature of the areas and ambulacral plates beveling over the interambulacra on the adradial sutures. Both ambulacral and interambulacral plates are thicker in the middle of their areas than at the adradial sutures. The inner face of the test presents a curve of one arc, thus differing from the exterior of the test where marked radial elevations occur in both ambulacral and interambulacral areas.

Lovenechinus mutatus (Keyes).

Page 335.

Figs. 10, 11 Keokuk Limestone, Lower Carboniferous, Keokuk, Iowa (after Keyes, 1894, Plate 15, figs. 4a, 4b).
 Holotype.

- Fig. 10. $\times 0.9$. Five columns of plates in an interambulacral area. Ambulacral fields are strongly elevated in melon-like ribs.
 Fig. 11. Same specimen, ambulacral detail enlarged. Plates occluded and demi-, a single row of tubercles only on a plate. The sutural contact of the demi- and occluded plates in each half-area is serrate, as in *L. septies* (Plate 45, fig. 3) not deeply reentrant and tongue-like, as in *L. nobilis*, fig. 5.

Figs. 1-3 copied by W. M. Barrows; figs. 4-9 drawn by J. Henry Blake; figs. 10, 11 from Keyes.

- Figs. 1, 2, 4-6. Burlington Group, Lower Carboniferous, Webb City, Missouri. Silicified internal molds with sutures bounding the plates represented by elevated walls and pores by siliceous plugs or tubes.
- Fig. 1. Mus. Comp. Zoöl. Coll., 3,140 (from R. T. J. Coll.). Natural size. Young individual. Initial plate of column 5 in area A is at the mid-zone. The apical disc measures proportionately about 20 % of the diameter of the test. Drawings, Plate 40, figs. 1, 2; Plate 41, fig. 2 (p. 341).
- Fig. 2. Same specimen, enlarged. $\times 1.4$.
- Fig. 3. Burlington Group, Lower Carboniferous, Joplin, Missouri. F. Braun Coll. Natural size. Medium sized specimen. Five columns of plates in all interambulacral areas, oculars and genitals all in place, the latter with four or five pores each. The apical disc measures proportionately about 21 % of the diameter of the test. Drawing, Plate 41, fig. 3 (p. 342).
- Fig. 4. Mus. Comp. Zoöl. Coll., 3,128 (from R. T. J. Coll.). Natural size. Old-age individual. Ventral view; ambulacral plates ventrally are all primaries, higher up demi- and occluded; five columns of plates in interambulacral areas A and C; a sixth column is represented by one or two plates in areas E, G, and I. Imperfect molds of jaws orally (p. 342).
- Fig. 5. Same specimen, dorsal view. Natural size. Ambulacral plates at the mid-zone are demi- and occluded, but near the apical disc all plates are primaries. Column 5 drops out dorsally in four interambulacral areas, also columns 1 and 2 in part are incomplete dorsally (compare Plate 42, fig. 6). The apical disc is small measuring proportionately about 16 % of the diameter of the test. Oculars are all in place and against them the youngest interambulacral plates are in contact. Genitals are all in place, each with three or four pores, which are represented by tubular siliceous casts of the original pores. There are impressions of a few periproctal plates. The bounding margins of each plate are represented by thin siliceous walls as seen best in interambulacra E and G (p. 22). Drawings of figs. 4 and 5: Plate 41, fig. 1; Plate 42, figs. 6, 7 (p. 342).
- Fig. 6. Mus. Comp. Zoöl. Coll., 3,131 (from R. T. J. Coll.). Natural size. Shows ambulacral plates, all primaries ventrally; higher up, occluded and demi-plates. Plates opposite the horizontal sutures of adradial plates are fan-shaped in this internal view. Drawing, Plate 42, fig. 5 (p. 346).

PLATE 40.

Lovenechinus missouriensis (Jackson).

Page 337.

- Fig. 1. Same specimen as photographs, Plate 39, figs. 1, 2. $\times 2.5$. A young specimen, the youngest of any known Palaeozoic echinoid, restored in part as indicated by dotted lines. There are fewer horizontal rows of interambulacral plates than in the adult, only thirteen or fourteen plates in each of the adradial columns, therefore the point of origin of column 5 is relatively much higher up than in an adult. In area E, column 5 is represented by only one plate, and in area I, a sixth column is represented by a small plate dorsally. The oculars have each a pore and cover the ambulacra and laterally the interambulacra in part on either side as usual (p. 341). For a view of the apical disc of this specimen see Plate 41, fig. 2.
- Fig. 2. Same specimen. $\times 2.6$. Drawn from a wax cast of a mold of the exterior, showing the ventral part of area E with the introduction of columns 3 and 4, and tubercles; also ventrally, ambulacral plates, which at this zone are all primaries.
- Fig. 3. Burlington Group, Lower Carboniferous, Webb City, Missouri. $\times 2.7$. Mus. Comp. Zool. Coll., 3,078, holotype. Ocular and genital plates enlarged. (Compare text-fig. 244, p. 338.)

Figs. 1 and 2 drawn by J. Henry Blake; fig. 3 by J. H. Emerton.

PLATE 41.

Lovenechinus missouriensis (Jackson).

Page 337.

- Fig. 1. Same specimen as photographs, Plate 39, figs. 4 and 5. $\times 0.7$. In the ambulaera, the plates ventrally are all primaries, at the mid-zone demi- and occluded, near the ocular all primaries. The bases of the interambulacra are in part restored as indicated by dotted lines. In area A, the third plate, P, of column 3 is by exception a pentagon, and its wanting side is compensated for by an adjacent heptagonal plate, H; the initial plate of column 5 is in the eighth row, next it is an exceptional pentagon, P. In the ninth row there are only four plates, but an octagonal plate, O, compensates for the sides wanting in the two adjacent pentagons, 5 and P. In area C, column 5 originates to the left of the center, an exception; a peculiar pentagonal plate, P, in column 4 is compensated for by an adjacent heptagonal plate, H. In area E, a sixth column is represented by a single plate 6, associated with which are a pentagonal plate, P, and two heptagonal plates, H, in column 5. A similar condition exists in area I. In area G, the sixth column is represented by two plates, 6, 6, with an associated pentagonal plate, P, and two heptagonal plates, H. In this specimen there are 26 plates in an adradial column, whereas in the young specimen, Plate 39, fig. 1; Plate 40, fig. 1, there are but 13 or 14 plates in an adradial column. This larger specimen is about three times as large as the smaller specimen yet there are only about twice as many plates in an adradial column. Here as I previously showed (Jackson, 1899, p. 130) in *Strongylocentrotus* and *Arbaeia* the increase of size in growth of the individual is attained proportionately more by an increase in the size of the plates than it is by the increase in the number of rows of plates (p. 342).
- Fig. 2. Same specimen as photograph, Plate 39, figs. 1, 2, also Plate 40, figs. 1, 2. Young individual. $\times 4.3$. Ambulacral plates are all primaries dorsally. Interambulacra abut against the oculars laterally. Oculars D and F are exsert, but all others apparently reach the periproet (p. 89); an ocular pore is in each plate in this internal view, but whether the pores reached the surface is doubtful; probably they did not (p. 89). Genitals A, C, and G have three pores each; the pores of the other genitals are doubtful (p. 341).
- Fig. 3. Same specimen as photograph, Plate 39, fig. 3. $\times 2.1$. Column 5 drops out dorsally in areas A to E, but reaches the apical disc in areas G and I. Oculars are all insert; genitals have four or five pores each, an unusually large number for the species (p. 342).

PLATE 42.

Lovenechinus missouriensis (Jackson).

Page 337.

- Figs. 1-4. Burlington Group, Lower Carboniferous, Burlington, Iowa. F. Springer Coll., 8,126. An exceptional specimen for surface characters, as most specimens are internal or external silicified molds. Same specimen as photograph, Plate 46, fig. 4 (p. 340).
- Fig. 1. A perfect ventral area to show developing stages. $\times 3.3$. Ambulacral plates ventrally are primaries, and pore-pairs are uniserial; a little higher up ambulacral plates are alternately primaries and ocluded and pore-pairs are biserial; at the upper part of this figure the plates are demi- and ocluded, and pore-pairs biserial, here having attained the full generic character. In the interambulacrum there are two plates in the basicoronal row, three plates in the second row, and four plates in the third row, as usual in this family (p. 340).
- Fig. 2. Ambulacrum near the mid-zone in area F. $\times 3.3$. Demi-plates are all narrow, and ocluded are wide; pore-pairs lie near the interambulacral suture (p. 340). (Compare text-fig. 18, p. 59.)
- Fig. 3. Dorsal portion of ambulacrum D to show localized stages. $\times 3.3$. In the lower part of the figure, ambulacral plates are demi- and ocluded, as is the typical character at the mid-zone. At the zone X, plates are primaries and ocluded, with pore-pairs biserial; passing dorsally, with some local irregularities, near the apical disc, at the zone XX, the plates are all primaries and pore-pairs are uniserial, as are the plates built in the youth of the individual, fig. 1. (Compare text-fig. 237, p. 231.) At Y in each half-area occur a few isolated plates. Such have not been observed in any other specimen of the genus, and as a progressive variation, are directly comparable to the typical character of *Oligoporus* (p. 341). (Compare figs. 1-4 with text-fig. 237, p. 231.)
- Fig. 4. Ambulacral plates near the mid-zone enlarged for surface details. $\times 6.7$. A relatively larger tubercle is on the inner tongue-like end of each demi-plate (p. 340).
- Fig. 5. Same specimen as photograph, Plate 39, fig. 6. Internal mold. $\times 2.5$. Ambulacral plates ventrally are all primaries; higher up are demi- and ocluded; plates opposite the interambulacral sutures are fan-shaped; the pore-pairs are in the middle of the half-areas. Compare fig. 1 for internal and external characters at the same zone, also Plate 43, figs. 1-5 (p. 346).
- Fig. 6. Same specimen as photograph, Plate 39, fig. 5, also Plate 41, fig. 1, dorsal area. $\times 2.5$. In interambulacral areas A, E, G, and I, column 5 drops out dorsally. In area I, the plates of columns 1 and 2 are developed to the apical disc, but do not reach the surface, being roofed over by the lateral extension of the plates of columns 3 and 4 (seen diagrammatically in fig. 7). Oculars all reach the periproct and pores exist in oculars H and J (p. 89). Genitals have three or four pores each. A few polygonal periproctal plates are in place, a very rare feature to be preserved and the only case known in this genus (p. 343).
- Fig. 7. Diagrammatic section of areas H, I, and J, drawn in the line of the arrow in fig. 6. Ambulacral plates bevel over the interambulacral plates of columns 1 and 2, which are ocluded from the surface by the lateral extension of the plates of columns 3 and 4. The ocluded plates marked X and * are the same plates as those that are similarly marked in fig. 6. (Compare Plate 39, fig. 5.)

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PLATE 43.

Lovenechinus missouriensis (Jackson).

Page 337.

Figs. 1-5. Same specimen as the photographs of an internal and external mold, Plate 44, figs. 3 and 4 (pp. 344-346).

- Fig. 1. Drawn from a wax cast of the external mold. $\times 2.6$. Ambulacral plates ventrally are all primaries with pore-pairs uniserial; higher up plates are alternately primaries and nearly or quite occluded (seen better in Plate 42, fig. 1). Dorsally, plates are demi- and occluded, the pore-pairs biserial. In all ambulacral plates the pores lie near the interambulacral suture; tubercles are numerous, of uniform size. In all interambulacral areas there are two plates in the basicoronal row, three plates in the second, and four plates in the third row, the fifth column coming in later in the sixth or seventh row. In area I the initial plate of column 5 is tetragonal, a rare variation, and to compensate for the two sides wanting in this plate there are two heptagonal plates, H, lying on its left and right ventral border (compare the similar condition in the introduction of the ninth column in *Oligoporus*, Plate 50, figs. 2, 3, and *Melonechinus*, Plate 59, fig. 14).
- Fig. 2. Drawn directly from the internal silicified mold, representing the interior of the same plates of which fig. 1 shows the exterior. $\times 2.6$. Ambulacral plates ventrally are all primaries; at the zone XX in area J, plates are alternately primaries and occluded; whereas on the exterior at the same zone, the plates are demi- and occluded (p. 60). Plates opposite interambulacral sutures are fan-shaped, which is not true of the exterior. Pore-pairs are in the middle of the half-area, whereas they are near the interambulacral suture on the exterior. Interambulacral plates are similar to the same plates of the external view, but are somewhat dislocated.
- Fig. 3. Drawn from a wax cast of the external mold at the mid-zone, representing the detail of a half-ambulacrum and the tenth and eleventh plates from the base of the adradial column of area I. $\times 2.6$. Ambulacral plates are demi- and occluded, pore-pairs are near the interambulacral suture, small tubercles are on all plates. (Compare text-fig. 11, p. 54.)
- Fig. 4. Drawn directly from the internal mold, representing the interior of the same plates as fig. 3. $\times 3$. Pore-pairs are in the middle of the half-area; demi-plates which are opposite the interambulacral horizontal sutures are fan-shaped (p. 60).
- Fig. 5. Drawn from a point in the specimen where the internal and external molds are in place and the former mass of the original plates exists as cavities. $\times$ about 5. On the exterior, tubercles are in place, ambulacral plates bevel over the adradials. The pores of ambulacral plates are represented by delicate siliceous rods which pass from the middle of the half-area proximally to near the interambulacral suture distally, a unique condition of preservation.

Oligoporus (?) *minutus* Beede.

Page 450.

- Fig. 6. Deer Creek Limestone, Carboniferous (Coal Measures), northeast of Topeka, Kansas (after Beede, 1899, Plate 32, fig. 3). Holotype. $\times 0.9$.

Figs. 1-5 drawn by J. Henry Blake; fig. 6 copied by W. M. Barrows.

PLATE 44.

Lovenechinus missouriensis (Jackson).

Page 337.

- Fig. 1. Burlington Group, Lower Carboniferous, Webb City, Missouri. Mus. Comp. Zool. Coll., 3,136 (from R. T. J. Coll.). Natural size. A moderate sized individual of uncompressed spherical form. There are five columns of plates in each of the five interambulacral areas; orally imperfect impressions of the lantern are in place.
- Fig. 2. Burlington Group, Lower Carboniferous, Coriscana, Missouri. Yale Mus. Coll., 314. Natural size. Internal mold of medium sized specimen. Five columns of plates in each interambulacral area, oculars (not shown in the figure) all insert (p. 344).
- Fig. 3. Burlington Group, Lower Carboniferous, Webb City, Missouri. Mus. Comp. Zool. Coll., 3,125 (from R. T. J. Coll.), paratype. Natural size. Internal siliceous mold, with boundaries of plates marked by more or less elevated ridges and pores by siliceous styles. Five columns of plates in each interambulacrum. In area A, there are two plates in the basicoronal row, three plates in the second row, four plates in the third row, and five plates in the sixth row. A heptagonal plate lies ventrally on the right of the initial plate of column 5 as usual, excepting in area I in which the initial plate of column 5 is tetragonal with two associated heptagonal plates as shown in Plate 43, figs. 1, 2. Drawings, Plate 43, figs. 2, 4, and 5 (pp. 344-346).
- Fig. 4. Same specimen. Natural size. External siliceous mold, with impressions of plates, tubercles, etc. This specimen consisting of an external and an internal mold, presents a condition and perfection of preservation of parts that are unique in Palaeozoic Echini. Drawings, made from wax casts of this external mold, Plate 43, figs. 1 and 3, are compared directly with those made from the internal mold, Plate 43, figs. 2 and 4. The specimen is therefore drawn as if viewed in optical section for comparison of internal and external characters (p. 345).
- Fig. 5. Same horizon and locality. Mus. Comp. Zool. Coll., 3,128 (from R. T. J. Coll.). Natural size. External siliceous mold, with outlines of plates and tubercles as impressions (p. 346).

Lovenechinus septies sp. nov.

Page 348.

- Fig. 6. Warsaw Group, Lower Carboniferous, Boonville, Missouri. F. Springer Coll., 8,115 (from G. Hambach Coll.), holotype. Enlarged, $\times 1.5$. An exceptionally perfect specimen for the Palaeozoic, ventral view. The interambulacral columns as introduced by pentagonal plates with associated heptagonal plates, are marked on the specimen in ink.
- Fig. 7. Same specimen enlarged, $\times 1.5$. Dorsal view. Drawings of this specimen, Plate 45, figs. 1-6.

PLATE 45.

Lovenechinus septies sp. nov.

Page 348.

Figs. 1-6. Same specimen as photographs, Plate 44, figs. 6 and 7. Holotype.

- Fig. 1. Specimen drawn spread out on the Lovén method. $\times 1.5$. Ambulacral plates ventrally are all primaries, pore-pairs uniserial; at the mid-zone plates are demi- and ocluded, with pore-pairs biserial. The interambulaera are remarkably perfect, but are restored partially as indicated by dotted lines. There are in each interambulaerum two plates in the basicoronal row, three plates in the second row, and four plates in the third row, excepting area C, in which, by rare exception, the fourth column does not originate until the fourth row. The initial plate of column 3 is hexagonal as usual in four areas, but in area C it is pentagonal (p. 68). Column 5 originates in the middle line of each area, in the sixth row in four areas, but in the seventh row in area C. Column 6 originates at or below the ambitus, and on the right of the center in areas A and G; but on the left of the center in areas C, E, and I. Column 7 originates above the ambitus and in the center line of each area. A heptagonal plate lies on the left or right ventral border of the initial plate of each column above the fourth. In area E there is an extra heptagon, H, due to an exceptional pentagonal plate, P, in column 6. Ocular and genital plates are in place dorsally.
- Fig. 2. Shows primary ambulacral plates ventrally, which are succeeded by demi- and ocluded plates. The ventral developing stages of the ambulaerum are not as complete as in the lower species *Lovenechinus missouriensis*, Plate 42, fig. 1. In the interambulaera the ventral developing stages are shown in two areas. $\times 4.4$. (Compare text-fig. 17, p. 59.)
- Fig. 3. Section of ambulaerum at the mid-zone. Pore-pairs biserial in peripodia; the suture line of the ocluded and demi-plates is serrate, not tongue-like as in *L. missouriensis*, Plate 42, fig. 2. $\times 4.4$.
- Fig. 4. Showing primary ambulacral plates next the apical disc and an ocular plate covering the ambulaerum and laterally the interambulacra in part on either side. $\times 4.4$.
- Fig. 5. Section looking ventrally, showing the relative thickness of plates and ambulacrals beveled over the adambulacrals on the adradial sutures. Interambulacral plates are shaded for contrast. $\times 3$.
- Fig. 6. Genital and ocular plates with the dorsal contact of the coronal plates against the same. $\times 4.5$.

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PLATE 46.

Maccoya gigas (M'Coy).

Page 321.

- Figs. 1, 2. Arenaceous shale, Lower Carboniferous, Rahan's Bay, Dunkineely, County Donegal, Ireland. Griffith Collection, Science and Arts Museum, Dublin. Cotype. Natural size. Original of M'Coy's, 1844, Plate 24, fig. 1. In fig. 1, the obverse side, are parts of an ambulacrum and three columns of interambulacral plates. In fig. 2, the reverse side, the plates are flattened back like a hinge on the line of the adradial suture; in this view parts of two columns of interambulacral plates are in place, with in addition some dissociated plates. Drawing, after Baily, Plate 47, fig. 2.
- Fig. 3. Same horizon, locality, and museum. Cotype. Natural size. Original of M'Coy's, 1844, Plate 44, fig. 4b. Two interambulacral plates. Surface ornamentation very clear.

Lovenechinus missouriensis (Jackson).

Page 337.

- Fig. 4. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. F. Springer Coll., 8,126. Natural size. One of only two specimens of this species known from other than Missouri localities. Ambulacral detail very clear. Five columns of plates in each interambulacral area. Drawings, Plate 42, figs. 1-4 (p. 340).

Lovenechinus anglicus sp. nov.

Page 346.

- Fig. 5. Lower Carboniferous Limestone, Clitheroe, Lancashire. Museum of Practical Geology Coll., London, 6,576, holotype. Natural size. Ambulacrum B represents the right half of its area; ventrally plates are alternately primary and occluded; higher up and for most of the area, the plates are alternately demi- and occluded. Ambulacrum D represents ventrally a fragment of the left half of its area, and farther dorsally the whole width of the area somewhat imperfectly. Interambulacral plates are very large, but relatively thin. For further description see drawings, Plate 47, figs. 3-5.
- Fig. 6. The same specimen. Interambulacral plate showing tubercles and spines. $\times 3$.

Figs. 1-3 from photographs taken by A. C. Bridle, in Dublin; fig. 5 by J. W. Tutecher; fig. 4 by H. W. Tupper; fig. 6 drawn by G. C. Chubb.

PLATE 47.

Maccoya gigas (M'Coy).

Page 321.

- Fig. 1. Lower Carboniferous, Rahan's Bay, Ireland. Sedgwick Museum Coll., Cambridge, England, 3 (drawn from the original specimen of Keeping's, 1876, Plate 3, fig. 13). $\times 4.7$. Ambulacral plates are alternately primaries and ocluded, pore-pairs biserial.
- Fig. 2. After Baily, 1877, Plate 3, fig. C. Same specimen as photograph, Plate 46, fig. 1. Cotype. $\times 1.6$. All ambulacral plates reach the middle of the area, but alternate plates are primaries, meeting the interambulacrum, or ocluded plates, which are cut off from interambulacral contact; pore-pairs biserial.

Lovenechinus anglicus sp. nov.

Page 346.

- Fig. 3. Same specimen as Plate 46, fig. 5. Holotype. $\times 0.9$. This specimen, well preserved in many points, presents a curious ease showing how parts may be shifted about. Interambulacrum A and the right half of ambulacrum B are quite complete; the left half of ambulacrum B and a large part of interambulacrum C are pushed to the right under the adjacent areas. In interambulacrum A there were at least six columns of plates; column 2 is assumed as indicated by dotted lines. In ambulacrum B ventrally the plates are primary and ocluded, seen also ventrally in area D; higher up the plates are all demi- and ocluded. This specimen is apparently the original of that which was described and figured by Duncan, 1889, p. 198, text-fig. I, as *Palaeochinus gigas*. Further, it is the original which I described and figured as *Palaeochinus gigas* (see Jackson, 1896, p. 204, Plate 7, figs. 38, 39).
- Fig. 4. Same specimen. Ambulacral plates from the ventral region. $\times 3.5$. All plates meet the middle of the area, but alternate plates are primaries, meeting the interambulacrum and ocluded, which are cut off from interambulacral contact. Compare Plate 42, fig. 1.
- Fig. 5. Same specimen, ambulacral plates from near the mid-zone. $\times 3.6$. The ocluded plates alone meet the middle of the area, demi-plates are narrower, laterally meeting the interambulacrum, and on their inner border fit between the outer ends of the ocluded plates in a tongue-like fashion.

Oligoporus blairi Miller and Gurley.

Page 351.

- Fig. 6. Same specimen as photograph, Plate 48, fig. 1. $\times 2.3$. The holotype of *Oligoporus bellulus* Miller and Gurley, here considered a synonym of *blairi*. Ambulacrum with four columns of plates, demi- and ocluded, also scattered isolated plates near the middle line of the half-areas. In area A there are four columns of interambulacral plates, a ease of extreme arrested radial variation; in another area, C, of this specimen, which is only preserved dorsally, there are seven columns of interambulacral plates. Tubercles and spines are shown on one interambulacral plate.
- Fig. 7. Same specimen as photograph, Plate 49, fig. 1. Cotype of *O. blairi*. $\times 2.4$. Section just above the mid-zone, ambulacrum with ocluded, demi-, and scattered isolated plates, seven columns of plates in interambulacrum A.

Oligoporus coreyi Meek and Worthen.

Page 353.

- Fig. 8. Same specimen as photograph, Plate 48, fig. 2. Holotype. $\times 2.4$. Section of an interambulacrum at the mid-zone showing six columns and the initial plate of a seventh column with its adjacent heptagon.
- Fig. 9. Same specimen and areas at the mid-dorsal portion. $\times 2.3$. Interambulacral columns have dropped out to five, ambulacrum with wide ocluded, proportionately rather wide demi-, and scattered isolated plates.

Oligoporus sulcatus Miller and Gurley.

Page 354.

- Fig. 10. Same specimen as photograph, Plate 48, figs. 3, 4. Holotype. $\times 2.3$. Section near the mid-zone, ambulacrum with ocluded, demi-, and scattered isolated plates, seven columns of interambulacral plates in area I; the initial pentagon of column 7 with its adjacent heptagon appears in this view. Only the left half of ambulacrum H is shown, and as the sutures of plates are obscure they are in part shown by dotted lines.

Oligoporus halli sp. nov.

Page 355.

- Fig. 11. Same specimen as photograph, Plate 48, fig. 5. Holotype. $\times 0.9$. The ambulacrum near the mid-zone with ocluded, demi-, and scattered isolated plates; eight columns of plates in interambulacral area C. In interambulacrum A the first two rows are restored as indicated by dotted lines. Column 3 originates in the second row, column 4 in the third row, and column 7 to the left of the center. In area C column 8 originates at about the mid-zone.
- Fig. 12. Same specimen; enlargement of ambulacral detail. $\times 2.3$.

Oligoporus danae (Meek and Worthen).

Page 356.

- Fig. 13. Keokuk Group, Lower Carboniferous, Jersey County, Illinois. F. Springer Coll. 8,124. $\times 2.3$. Plates with spines in place.

Figs. 1, 2, 6-13 drawn by J. Henry Blake; figs. 3-5 by G. C. Chubb.

13

11

PLATE 48.

Oligoporus blairi Miller and Gurley.

Page 351.

- Fig. 1. Keokuk Group, Lower Carboniferous, Boonville, Missouri. Univ. of Chicago Coll., 6,190 (the holotype of *Oligoporus bellulus* Miller and Gurley, here considered a synonym of *blairi*). Natural size. Ambulacral plates at the mid-zone are demi- and ocluded, with scattered isolated plates. In interambulacrum A there are only four columns of plates, an extreme radial arrested variation; interambulacrum C is only preserved dorsally, but at that zone there are seven columns of plates in this area. Some tubercles and spines are in place on ambulacral and interambulacral areas. Drawing, Plate 47, fig. 6.

Oligoporus coreyi Meek and Worthen.

Page 353.

- Fig. 2. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana. Univ. of Michigan Coll., 147, holotype. Natural size. Dorsal view; the specimen is silicified, and the surface is worn, so that details are clear only in parts. Ambulacra with demi-, ocluded, and scattered isolated plates. In interambulacra A, E, and G, there are seven columns of plates, but in C there are only six columns. In area I only six columns are visible but the area is imperfect dorsally. Drawings, Plate 47, figs. 8, 9.

Oligoporus sulcatus Miller and Gurley.

Page 354.

- Fig. 3. St. Louis Group, Lower Carboniferous, Hardin County, Kentucky, Univ. of Chicago Coll., 6,623, holotype. Natural size. Silicified specimen, ventral view.
- Fig. 4. Same specimen, dorsal view. Natural size. Melon-like ribs are strongly marked. Ambulacra with demi-, ocluded, and scattered isolated plates. All interambulacra with six columns of plates at the mid-zone, but with a seventh arising just above that zone in each area. Drawing, Plate 47, fig. 10.

Oligoporus halli sp. nov.

Page 355.

- Fig. 5. Keokuk Group, Lower Carboniferous, Boonville, Missouri. F. Springer Coll., 8,114, holotype (from G. Hambach Coll., the original of Miss Klem's 1904, Plate 1, figs. 3a, 3b). Natural size. Melon-like ribs moderately developed. Ambulacra with demi-, ocluded, and scattered isolated plates. Interambulacra A, C, and I each have eight columns of plates, but E and G have only seven. Drawings, Plate 47, figs. 11, 12.

PLATE 49.

Oligoporus blairi Miller and Gurley.

Page 351.

Figs. 1-3. Keokuk Group, Lower Carboniferous, Boonville, Missouri. Univ. of Chicago Coll., 6,470, cotypes. Natural size. Melon-like ribs moderately developed, ambulacral plates demi-, occluded and scattered isolated.

Fig. 1. Interambulera A, C, and E each with seven columns of plates. Drawing of this specimen, Plate 47, fig. 7.

Fig. 2. In interambulacrum A there are six columns of plates, the initial pentagon of column 6 lying on the right of the center just below the mid-zone. In interambulacrum C there are seven columns of plates. The initial pentagon of column 5 is in the middle line near the ventral border; the initial pentagon of column 6 lies three rows above on the left of the center, and the initial pentagon of column 7 lies again three rows above in the center and just above the mid-zone.

Fig. 3. In interambulacrum A there are six columns of plates, the initial pentagon of column 6 with a heptagon on its right ventral border lying on the left of the center and below the mid-zone. In interambulacrum C the initial pentagon of column 6 lies on the left of the center and appears somewhat earlier than in area A. The initial pentagon of column 7 with a heptagon on its right ventral border appears just above the mid-zone. Above this zone on the right the plates are displaced and confused.

Oligoporus danae (Meek and Worthen).

Page 356.

Fig. 4. Keokuk Group, Lower Carboniferous, Adams County, Illinois. Mus. Comp. Zool. Coll., 3,142 (from R. T. J. Coll.). Natural size. Ambulacra with demi-, occluded, and scattered isolated plates. Interambulacra with nine columns of plates in each area, the ninth appearing at the mid-zone. Drawing, Plate 50, fig. 1.

Fig. 5. Same specimen, reverse side. Natural size. Both interambulacra with nine columns of plates. Drawings, Plate 50, figs. 2-6.

PLATE 50.

Oligoporus danae (Meek and Worthen).

Page 356.

- Fig. 1. Same specimen as photograph, Plate 49, fig. 4. $\times 0.8$. Restored ventrally as indicated by dotted lines; ambulacrum at the mid-zone with ocluded, demi-, and scattered isolated plates. Interambulacra each with nine columns of plates, the ninth originating at or below the mid-zone.
- Fig. 2. Same specimen and view as the photograph, Plate 49, fig. 5. $\times 0.8$. External view of interambulacrum E. The adradial plates show lateral beveling where, when in place, they are inclined over by the ambulacral plates (compare Plate 45, fig. 5). The ninth column originates in a tetragonal plate, the two wanting sides of which are compensated for by two ventrally adjacent heptagonal plates.
- Fig. 3. Same specimen and view as the photograph, Plate 49, fig. 5. $\times 0.8$. Internal view of interambulacrum I, restored ventrally as indicated by dotted lines. Curiously the ninth column originates in a tetragonal plate with two adjacent heptagons as in area E (fig. 2). It is rare for the initial plates of columns as introduced to be tetragonal but a similar case is shown in the ninth column in *Melonechinus*, Plate 59, fig. 14, and in the fifth column in *Lovenechinus*, Plate 43, fig. 2.
- Fig. 4. Same specimen; left half-ambulacrum from the area marked X, in fig. 1. $\times 2.5$. Demi-plates are wide, but the ocluded are wider, with scattered isolated plates.
- Fig. 5. Same specimen; right half-ambulacrum, from another area at the mid-zone. $\times 2.5$.
- Fig. 6. Same specimen; genital plate, with two oculars restored as indicated by dotted lines. $\times 2.5$. The genital plate has a strong bevel on its adoral face so that it is distinctly higher on the interior than it is on the exterior.
- Fig. 7. Keokuk Group, Lower Carboniferous, Keokuk, Iowa. Mus. Comp. Zool. Coll., 2,998. $\times 2.4$. Ambulacrum from the mid-zone, demi-plates are wide, but the ocluded are wider, scattered isolated plates. (Compare text-fig. 12, p. 54; also compare figs. 1, 7, and 8 with text-fig. 237, p. 231.)
- Fig. 8. Keokuk Group, Lower Carboniferous, Washington County, Indiana. F. Braun Coll. $\times 2.5$. Ventrally ambulacral plates are primaries only; higher up a few plates are primary and ocluded; higher still demi- and ocluded, but as yet no isolated plates have appeared. In the interambulacra there are two plates in the basicoronal row, three plates in the second row, and four plates in the third row, the fifth column originating in the fifth row; a few tubercles and spines are shown in area A.
- Fig. 9. Same specimen. $\times 2.5$. Left half-ambulacrum from a higher zone, showing the typical generic character with isolated plates in the middle of the half-area.
- Fig. 10. Keokuk Group, Lower Carboniferous, Jersey County, Illinois. F. Springer Coll., 8,124. $\times 3.3$. Interambulacral plate with secondary tubercles.
- Fig. 11. Lower Carboniferous, Missouri. Mus. Comp. Zool. Coll., 3,146 (from R. T. J. Coll.). $\times 2.5$. Pyramid in side view, with ridges for the attachment of interpyramidal muscles.
- Fig. 12. Same slab; pyramid. $\times 2.5$. An internal view, showing the dental slide, pyramidal suture, and an epiphysis in place.

PLATE 51.

Melonechinus dispar (Fischer von Waldheim).

Page 365.

Figs. 1-3. Lower Carboniferous Limestone, Ratofka, Moscow, Russia, after Fischer von Waldheim, 1848, Plate 3, figs. 4a-4d. Holotype.

Fig. 1. Probably magnified $\times 2$. Six columns of plates in the ambulacral areas and four columns of plates in the interambulacrum; structurally the simplest species known in the genus.

Fig. 2. Ambulacral plates enlarged; they are more hexagonal than in any specimens of other species seen.

Fig. 3. Single interambulacral plate with tubercles. Enlarged.

Melonechinus parvus (Hambach).

Page 365.

Fig. 4. Lower St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll., 8,118, holotype (from G. Hambach Coll.). Natural size. Ventral view, melon-like ribs are weakly marked; six columns of plates in each ambulacral area at the mid-zone and six columns of plates in interambulacrum A at a point a little dorsal to the mid-zone. Drawing, Plate 52, fig. 1.

Melonechinus springeri sp. nov.

Page 366.

Fig. 5. St. Louis Group, Lower Carboniferous, Elizabethtown, Kentucky. F. Springer Coll., 8,103, holotype. Natural size. A small species, with melon-like ribs strongly marked, six columns of plates in an ambulacral area at the mid-zone. In interambulacra E, G, and I there are six columns of plates, but in interambulacra A and C a seventh column is represented by a few plates dorsally. The apical disc measures proportionately about 23 % of the diameter of the test, which is relatively large for the genus and family (p. 367). Drawings, Plate 52, figs. 2-6.

Melonechinus crassus (Hambach).

Page 367.

Fig. 6. Lower St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll., 8,116, holotype (from G. Hambach Coll., the original of Miss Klem's, 1904, Plate 1, figs. 2a-2d). Natural size. A massive species, with strong rounded melon-like ribs. There are eight columns of ambulacral plates at the mid-zone and six columns of interambulacral plates in areas A, C, E, and G, but area I is imperfect dorsally so that the number of columns is uncertain. In the figure, the oral area is below. Hambach's published figure of this specimen is inverted. Drawings, Plate 52, figs. 7-11.

Melonechinus indianensis (Miller and Gurley).

Page 369.

Fig. 7. St. Louis Group, Lower Carboniferous, Greenville, Harrison County, Indiana. Univ. of Chicago Coll., 6,622, holotype. Natural size. Melon-like ribs strongly marked, a large, old-age individual. Eight columns of plates in an ambulacral area at the mid-zone. In interambulacra A to G there are six columns of plates, but in I there are seven columns and two plates representing an eighth column. The apical disc measures proportionately 16 % of the diameter of the test (p. 370). Oculars are all insert, genitals are wide and high. Drawings, Plate 53, figs. 1-4.

Fig. 8. St. Louis Group, Lower Carboniferous, Greenville, Harrison County, Indiana. F. Braun Coll. Natural size. There are six columns of plates in each interambulacral area. The apical disc measures proportionately 18 % of the diameter of the test.

Fig. 9. Lower Carboniferous, Allen County, Kentucky. Mus. Comp. Zool. Coll., 3,147. Natural size. Eight columns of plates in each ambulacral area, and six columns of plates in each interambulacral area. The sutures of the plates are a good deal obscured by silicification.

Melonechinus septenarius Jackson.

Page 373.

Fig. 10. Warsaw Group, Lower Carboniferous, Buzzard's Roost, Franklin County, Alabama. Amer. Mus. Nat. Hist., ⁷⁵¹⁷/₁, holotype. Natural size. The specimen is a siliceous internal mold, therefore the surface character is unknown; eight columns of plates in the ambulacral area at the mid-zone and seven columns of plates in the interambulacral area. Drawing, Plate 53, fig. 5.

Fig. 10 from photograph taken in New York; all others by F. A. Saunderson.

PLATE 52.

Melonechinus parvus (Hambach).

Page 365.

- Fig. 1. Same specimen as photograph, Plate 51, fig. 4. Holotype. $\times 1.8$. Six irregular columns of ambulaeral plates at the mid-zone. In area B as far adorally as it is preserved there are two columns of plates, demi- and ocluded in the right half-area, higher up dissociated isolated plates appear, higher again the isolated plates become more frequent and make a continuous column, thus forming with the demi- and ocluded plates three columns in a half-area, the species character. In interambulaerum A (restored ventrally, as indicated by dotted lines) there are five columns of plates at the mid-zone. A sixth column appears dorsally represented by one pentagonal plate with a heptagon, H, on its left ventral border. In area C a peculiar pentagonal plate, X, appears in column 4, and the adradial plate on its right has six instead of five sides as is usual in the plates of an adradial column.

Melonechinus springeri sp. nov.

Page 366.

Figs. 2-6. Same specimen as photograph, Plate 51, fig. 5. Holotype.

- Fig. 2. Upper part of the test. $\times 3.6$. In the half-ambulaera there are three irregular columns of plates at the mid-zone, higher up two columns with dissociated isolated plates, then two columns only and near the ocular one column only in a half-area. Interambulaerum with six columns of plates at the mid-zone, a seventh appearing dorsally in this area and also in area C. (Compare fig. 2 with text-fig. 19, p. 59; and figs. 2 and 3 with text-fig. 237, p. 231.)
- Fig. 3. Half-ambulaerum ventrally. $\times 3.6$. Two columns of demi- and ocluded plates ventrally, higher up an isolated plate appears, then more isolated plates appear making three columns in the half-area.
- Fig. 4. Interambulaerum I, restored ventrally, as indicated by dotted lines, showing the introduction of columns 5 and 6. $\times 1.8$.
- Fig. 5. Ambulaeral plates, showing tubercles and pore-pairs in peripodia. $\times 7$.
- Fig. 6. Interambulaeral plate with tubercles. $\times 7$.

Melonechinus crassus (Hambach).

Page 367.

Figs. 7-11. Same specimen as photograph, Plate 51, fig. 6. Holotype.

- Fig. 7. Interambulaerum C with a half-ambulaerum at the mid-zone. $\times 1.3$. Column 1 is partially restored, as indicated by dotted lines. Columns 5 and 6 originate early; ambulaerum with four columns of plates in the half-area at the mid-zone.
- Fig. 8. Ventral part of interambulaerum E. $\times 1.3$. The basicoronal row is restored, as indicated by dotted lines; there are three plates in the second row, and four in the third, the fifth column appearing in the seventh row.
- Fig. 9. Base of ambulaerum F. $\times 3.5$. Ventrally, there are demi- and ocluded plates only, higher up isolated plates appear in the middle line of the half-area. Compare the ventral plates of ambulaerum B in fig. 7.
- Fig. 10. Spines in ambulaerum B. $\times 7.2$.
- Fig. 11. Spines in interambulaerum C, from area marked X in fig. 7. $\times 7.1$.

Melonechinus indianensis (Miller and Gurley).

Page 369.

Figs. 1-4. Same specimen as photograph, Plate 51, fig. 7. Holotype.

- Fig. 1. Dorsal portion spread out. $\times 3.4$. In ambulacrum F there are four columns of plates in a half-area as far ventrally as it is shown and the number decreases passing dorsally to the apical disc. Interambulacral columns 1 and 2 drop out dorsally, indicating senescence, and some additional columns drop out as column 6 in area G and column 4 in area C. Oculars are all insert and adorally cover the ambulacra and laterally the interambulacra in part on either side. Three genital pores in one plate, and in the other genital plates the pores are partly or wholly obliterated by the process of silicification.
- Fig. 2. Ventral part of the left half of ambulacrum J. $\times 3.4$. Ventrally the plates are all demi- and ocluded; higher up isolated plates appear, then three columns, and at the top of the figure there are four columns in the half-area, the species character.
- Fig. 3. Ambulacrum J at the mid-zone. $\times 3.4$. Four columns of plates in a half-area; pore-pairs are in peripodia, tubercles on the interambulacral plates. (Compare figs. 1-3 with text-fig. 237, p. 231.)
- Fig. 4. Interambulacrum I. $\times 0.8$. Partially restored ventrally and on each side as indicated by dotted lines. In the basicoronal row there are two plates (restored), three plates in the second row, and four in the third, column 5 originating in the seventh row with a tetragonal plate, a rare occurrence, and to compensate for the two sides wanting there are two adjacent heptagonal plates, H, H. Column 6 originates two rows above the fifth with a pentagonal plate, with an adjacent heptagon on its left ventral border. The seventh column appears at the mid-zone, and an eighth column is represented by two plates. All other interambulacral areas of this specimen have six columns of plates.

Melonechinus septenarius (Jackson).

Page 373.

- Fig. 5. After Jackson, 1896, Plate 9, fig. 49. Same specimen as photograph, Plate 51, fig. 10. Holotype. $\times 1.3$. There are four columns of plates in a half-ambulacrum, and seven columns of plates in an interambulacral area. The seventh column originates between columns 2 and 4, a peculiar exception.

Melonechinus stewartii (Safford).

Page 371.

- Figs. 6-8. Drawn from the original specimen which is an external mold, therefore the lettering of the figures is reversed. A photographic figure of a plaster cast of the type is shown in Plate 54, fig. 1, holotype.
- Fig. 6. Half-ambulacrum near the mid-zone. $\times 3.5$. Four columns of plates in the half-area; pore-pairs are in peripodia, tubercles on ambulacral and interambulacral plates.
- Fig. 7. Spines. $\times 3.4$.
- Fig. 8. Dorsal half of interambulacrum G. $\times 0.9$. Seven columns of plates in the area, the seventh appearing above the mid-zone.

Melonechinus obovatus sp. nov.

Page 373.

Figs. 9, 10. Same specimen as photograph, Plate 54, figs. 2, 3. Holotype.

- Fig. 9. Structure at the mid-zone. $\times 2.6$. Five columns of irregular plates in an ambulacral half-area. As this is an internal mold, the pores do not lie near the interambulacrum (compare Plate 56, figs. 4, 5). Only three columns of plates occur in an interambulacral area, which is the fewest known as a species character in the genus or the family (pp. 417, 444).
- Fig. 10. Dorsal view. $\times 2.6$. Three columns of plates in each interambulacral area; impressions of insert oculars and genitals are all in place. The oculars adorally cover the ambulacra and laterally the interambulacra in part on either side.

Melonechinus liratus sp. nov.

Page 374.

- Fig. 11. Same specimen as photograph, Plate 54, fig. 4. Holotype. $\times 1.3$. Section at the mid-zone, showing five columns of plates in an ambulacral half-area, and eight columns of plates in an interambulacral area.

Fig. 5 drawn by J. H. Emerton; all others by J. Henry Blake.

PLATE 54.

Melonechinus stewartii (Safford).

Page 371.

- Fig. 1. Lower Carboniferous, probably St. Louis Group, Middle Tennessee, but the detailed locality is unknown. Plaster cast of the holotype, which is an external mold. Natural size. The holotype is in Vanderbilt Univ. Coll., 223. Eight columns of plates in an ambulacral area at the mid-zone. In each of the interambulacral areas A to G there are seven columns of plates, but in area I there are only six. The apical disc and periproctal plates are well preserved. The apical disc measures proportionately about 17 % of the diameter of the test. Drawing from the original molds, Plate 53, figs. 6-8, or directly from a wax cast of same, Plate 56, fig. 1.

Melonechinus obovatus sp. nov.

Page 373.

- Figs. 2, 3. Lower Carboniferous, White's Creek, Davidson County, Tennessee. Vanderbilt Univ. Coll. Holotype. Natural size. The specimen is an internal calcite mold, so that the melon-like ribs, which are a feature of the exterior in most species of the genus, are unknown. Ten columns of plates in an ambulacral area at the mid-zone. In the interambulacra there are only three columns of plates in each area at the mid-zone, the fewest known in the genus or family.
- Fig. 2. Side view, showing the peculiar obovate form, with the ambitus above the mid-zone, a very rare character in Echini (p. 32). Drawing, Plate 53, fig. 9.
- Fig. 3. Dorsal view. No melon-like ribs shown, this being an internal mold; oculars and genitals are all in place. The apical disc measures proportionately 25 % of the diameter of the test which is relatively very large for the genus (p. 374). Drawing, Plate 53, fig. 10.

Melonechinus liratus sp. nov.

Page 374.

- Fig. 4. Lower Carboniferous, locality unknown, but doubtless from Tennessee or Kentucky. Vanderbilt Univ. Coll., 221, holotype. Natural size. High, angular, melon-like ribs in ambulacral and interambulacral areas. Ten columns of plates in each ambulacral area and eight columns of plates in each interambulacral area. Drawing, Plate 53, fig. 11.

Melonechinus multiporus (Norwood and Owen).

Page 375.

- Fig. 5. St. Louis Group, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll., 8,112 (from G. Hambach Coll., K 12, the original of Miss Klem's, 1904, Plate 5, fig. 12d; Plate 6, figs. 12a-12c). Natural size. Low rounded melon-like ribs. In area A there are nine, but in all other interambulacral areas eight columns of plates (p. 384). The introduction of the eighth column is seen adorally in areas C and E. Oculars and genitals are clear. Oculars are insert and are in contact with the interambulacra laterally as seen clearly in area D. Genital A has four genital pores and the other four genitals have three pores each (p. 379).

PLATE 55.

Melonechinus multiporus (Norwood and Owen).

Page 375.

Figs. 1-3. St. Louis Group, Lower Carboniferous, St. Louis, Missouri.

- Fig. 1. F. Springer Coll., 8,106 (from G. Hambach Coll., K 6, the original specimen of Miss Klem's, 1904, Plate 3, figs. 6a-6e). Enlarged $\times 1.2$. Diameter through the plane J, E, 63 mm., height 57 mm. Ventral view, a small but marvellously perfect specimen. Melon-like ribs low, rounded. In four ambulacral areas the plates ventrally are in four columns there being two columns of demi-plates and two columns of occluded plates in each area as usual at this zone in the species and the genus, the number of columns in each area increasing in passing dorsally. As an exception in area B ventrally there are two primary plates representing two columns in this zone as a unique regressive radial variation. In interambulacrum G there are two plates in the basicoronal row, three plates in the second row, and four plates in the third row. The fifth column originates in the sixth row with a heptagon on the left border of the initial pentagon. The sixth column originates in the tenth row with a heptagon on the right of its initial pentagonal plate (compare Plate 57, fig. 1, and text-fig. 245, p. 382). The other interambulacral areas are similar except that the two plates of the basicoronal row are not complete in each area.
- Fig. 2. The same specimen, dorsal view. Enlarged $\times 1.2$. Eight columns of plates in each interambulacral area, and these plates dorsally approach a rhombic form. Insert ocular and genitals are all in place. The apical disc measures proportionately about 15% of the diameter of the test. Drawings of this exceptionally fine specimen, Plate 57, figs. 1-3; text-figs. 245, 246, p. 382. (See pp. 230, 376, 379, 381-384.)
- Fig. 3. F. Springer Coll., 8,109 (from G. Hambach Coll., K 9, the original specimen of Miss Klem's, 1904, Plate 4, fig. 9d; Plate 5, figs. 9a, 9b). Natural size. An exceptionally large specimen, the largest seen of this species. There are nine columns of plates in interambulacral areas C, E, and G. Four oculars and all genitals are well preserved. Oculars are insert and cover the ambulacra and laterally the interambulacra in part on either side, as seen in several areas. Genital E has three, and G four pores; the other genitals have apparently three pores each, but the number may be four in one or more of these plates as confusing accessory pits exist. The apical disc measures proportionately about 15% of the diameter of the test (pp. 376, 377, 379).

Melonechinus stewartii (Safford).

Page 371.

- Fig. 1. Same specimen as photograph, Plate 54, fig. 1. Drawn from a wax cast of the holotype which is an external mold. $\times 3.5$. Oculars and genitals are all in place, and in addition a number of polygonal periproctal plates are in place. This is the only specimen known in the genus in which the periproctal plates are known (p. 363).

Melonechinus multiporus (Norwood and Owen).

Page 375.

Figs. 2-13. St. Louis Group, Lower Carboniferous, St. Louis, Missouri.

- Fig. 2. After Jackson and Jaggar, 1896, Plate 2, fig. 3. Mus. Comp. Zool. Coll., 3,003. $\times 1.2$. A nearly perfect ventral area. There are four columns of plates in three of the ambulacra; in each interambulacrum there are two plates in the basicoronal row and three plates in the second row (p. 376).
- Fig. 3. After Jackson and Jaggar, 1896, Plate 2, fig. 4. Mus. Comp. Zool. Coll., 2,994. Development of an ambulacrum. $\times 3.5$. Ventrally there are four columns consisting of demi- and occluded plates, higher up scattered isolated plates appear in the middle of each half-area, still higher there are three, then four irregular columns of plates in each half-area (pp. 228, 376).
- Fig. 4. Vanderbilt Univ. Coll., 218. Ambulacrum at the mid-zone seen from the exterior. $\times 2.3$. Ten irregular columns of plates consisting of two columns of wide occluded plates, two columns of narrow demi-plates, and six irregular columns of isolated plates. Pore-pairs lie in that portion of each plate nearest to the next adjacent interambulacrum (p. 376). (Compare text-figs. 13, p. 54; 20, p. 59; also compare Plate 56, figs. 2, 3, 4, and 6 with text-fig. 237, p. 231.)
- Fig. 5. Mus. Comp. Zool. Coll., 3,164 (from R. T. J. Coll.). $\times 2.3$. Ambulacrum at the mid-zone, seen from the interior (compare fig. 4). The two median columns of occluded plates are narrower than on the exterior. In the lateral columns of demi-plates those lying opposite the horizontal interambulacral sutures are fan-shaped, which they are not on the exterior (compare Plate 43, figs. 3, 4). The ambulacral pore-pairs of occluded plates lie near the outer margin of each plate; in isolated plates the pore-pairs lie near the middle of each plate and in demi-plates they lie toward the inner margin of each plate, instead of all toward the next adjacent interambulacrum, as they do in all plates, when seen on the exterior (pp. 60, 376).
- Fig. 6. Mus. Comp. Zool. Coll., 3,158. (from R. T. J. Coll.). $\times 4.6$. In ambulacrum J there are six columns of plates as far ventrally as shown, higher up there are four columns, and next the ocular only two plates, representing two columns, a primitive character (compare text-fig. 237, p. 231). Other ambulacral areas are similar, but with a less complete reduction dorsally. Young interambulacral plates are in contact with the oculars. Ocular plates are all insert and adorally cover the ambulacra and laterally the interambulacra in part on either side. Genitals with three pores each (pp. 376, 379, 381). (Compare text-fig. 163, p. 149.)
- Fig. 7. Princeton Univ. Coll., 1,464. $\times 1.7$. Showing peristomal plates, the only specimen known in the genus or family with this character preserved. In the ambulacrum of the peristome there are two plates in an area orally, these I consider as representing the primordial ambulacral plates, as seen in areas J and D; passing aborally, the plates increase to many low small irregular plates in each area on the periphery of the peristome. Interradially there are three non-ambulacral plates in an area: one adorally, and two in a row aborally. The base of the corona is quite perfect, with four plates in the basicoronal row of each ambulacral area and two plates in the basicoronal row of each interambulacral area (p. 378).
- Fig. 8. The same restored, with teeth and pyramids (compare text-fig. 48, p. 80), (pp. 82, 85, 362, 378).
- Fig. 9. Mus. Comp. Zool. Coll., 3,165 (from R. T. J. Coll.). $\times 1.8$. A pyramid, with its ventral portion and tooth restored as indicated by dotted lines (pp. 363, 379).
- Fig. 10. F. Braun Coll. $\times 2$. Pyramids in place with teeth (p. 379).
- Fig. 11. After Jackson and Jaggar, 1896, Plate 5, fig. 20. Mus. Comp. Zool. Coll., 3,005. $\times 0.9$. Specimen with nine columns of plates in two interambulacral areas, the extreme highest number known in the species. Interambulacral plates rhombic dorsally and strung out so that succeeding plates of a given column are separated and not in serial contact as seen in the upper part of figure (p. 377).
- Fig. 12. Mus. Comp. Zool. Coll., 3,161. $\times 2.4$. Ambulacral plates with tubercles and pore-pairs in peripodia (p. 376).
- Fig. 13. After Jackson and Jaggar, 1896, Plate 2, fig. 1. Mus. Comp. Zool. Coll., 2,988. $\times$ about 5. Spines tapering. Some of the spines show slight constrictions, but these are quite probably accidental, as two other specimens of this species in the Museum of Comparative Zoology 2,996 and 3,079, with excellent spines show no evidence of such constrictions (p. 377).

Figs. 2, 7, 8, and 11 drawn by J. H. Emerton; fig. 13 by A. M. Westergren; all others by J. Henry Blake.

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Figs. 1-3. Same specimen as photographs, Plate 55, figs. 1, 2. The most perfectly preserved specimen of a Palaeozoic sea-urchin that I have seen, so that I am able to show it spread out by the Lovén method with every plate in place excepting a few which are restored in the basicoronal row of interambulacral areas A, C, and E, as indicated by dotted lines (pp. 381-384).

Fig. 1. Spread out to show five interambulacra and one ambulacrum complete from the basicoronal row to the apical disc. Natural size. In ambulacrum J, also D, F, and H, there are four plates in a row ventrally. Passing dorsally in J are found in addition dissociated isolated ambulacral plates in the middle of each half-area, then isolated plates become more frequent and are continuous, thus making three columns of plates in a half-area; next more isolated plates appear, making four columns of plates in a half-area; then still more series of isolated plates originate, making five columns in a half-area at the mid-zone, which is the specific character. Above the mid-zone we soon pass dorsally into an area with four plates in a row to a half-area, higher up only three plates in a row, and near the ocular plate only two plates in a row in each half-area, and in actual contact with the ocular there is only a single primary plate in each half-area, a simpler condition than that seen in the youthful plates ventrally (compare text-fig. 237, p. 231). In ambulacrum B there are only two plates ventrally, enlarged in fig. 3; this character of primary plates occurring in the ventral zone is a unique regressive variation for the genus as far as known. The ambulacral areas as in this figure are shown more enlarged in text-fig. 245, p. 382.

In interambulacra I and G there are two plates in the basicoronal row, but the plates of this lowest row are partly or wholly restored in the other three interambulacral areas, as indicated by dotted lines (compare text-fig. 245, p. 382). In all interambulacra the initial plate of column 3 is a hexagonal plate in the second row. In interambulacra A, E, and I the initial plate of column 4 is a pentagon in the third row on the right of the center, but in areas G and C this plate of the column 4 is on the left of the center. In interambulacrum I the initial plate of column 5 is a pentagon in the center in the seventh row, with a heptagonal plate on its right ventral border. In area G, pentagon 5 is in the sixth row with the heptagon on its left ventral border. In area E, pentagon 5 is in the seventh row with the heptagon on its right ventral border. In area C, pentagon 5 is on the left of the center in the sixth row with the heptagon on its right ventral border, and in area A the pentagon 5 is in the center in the sixth row with the heptagon on its right ventral border. In interambulacrum I the initial plate of column 6 is a pentagon on the right of the center in the tenth row with a heptagon on its left ventral border. In area G, pentagon 6 is also on the right of the center in the tenth row, but the heptagon is on its right ventral border. In areas E and A pentagon 6 is on the left of the center in the tenth row with the heptagon on the left ventral border. In area C, pentagon 6 is also on the left of the center, but in the ninth row with the heptagon on its right ventral border. In interambulacrum I the initial plate of column 7 is a pentagon in the center with a heptagon on its right ventral border. The initial pentagon of column 7 is in the center in all other areas with the heptagon on its right ventral border in area E, but on its left ventral border in areas G, C, and A. The seventh column originates in the fourteenth row in areas I and G, in the fifteenth row in area E, and in the thirteenth row in areas C and A. In interambulacrum I, the initial plate of column 8 is a pentagon on the right of the center, with a heptagon on its left ventral border. The initial pentagon of column 8 is on the left of the center in areas G, E, and A, but by rather rare exception in area C the initial plate of column 8 is a tetragonal plate, on the left of the center with two adjacent heptagons to compensate for its two sides wanting. The heptagon next to initial pentagon 8 is on its left ventral border in areas I, E, and G, but on its right ventral border in area A. The eighth column originates in the 18th row in areas I and C, in the 19th row in area G, in the 21st row in area E, and in the 17th row in area A. (Compare text-figs. 25, p. 70; 245 and 246, p. 382.) Dorsally in each area all the columns of interambulacral plates continue to the apical disc, but are strung out dorso-ventrally as is usual in that area (pp. 378, 381-384).

Fig. 2. Dorsal area. $\times 4$. Shows ambulacrum J, with two plates next to the ocular and the number of plates in a row increases passing ventrally. The young interambulacral plates are in contact with the lateral borders of ocular J on either side. Oculars are all imperforate and reach the periproct. Genital G has four pores; all other genitals have three pores each.

Fig. 3. Ventral part of ambulacrum B. $\times 4$. As a radial regressive variation, this area has a few primary plates extending across the half-area. Above these primary plates are demi- and occluded plates, which is the usual character of the ventral ambulacral plates in the genus. Primary plates are characteristic of Palaeochinus at the mid-zone, and also are characteristic as a ventral developing stage in Lovenechinus (Plate 42, fig. 1) and Oligoporus. For such primary plates to occur ventrally in Melonechinus is a case of extreme radial regressive variation and is a unique variant for the genus (pp. 19, 228, 360, 381).

PLATE 58.

Melonechinus keepingi sp. nov.

Page 384.

- Fig. 1. Lower Carboniferous Limestone, Gledstone, Gisburn, Yorkshire, England. Museum of Practical Geology, London, 6,583, holotype. Natural size. There are twelve columns of plates in an ambulacral area near the mid-zone. Just above the letter J are seen the two median columns of occluded plates, which are relatively narrow for the genus and not built up in melon-like ribs (pp. 359, 384). There are plates of ambulacrum B in place dorsally which serve to fix the limits of the interambulacrum. The interambulacrum has six columns of plates, but columns 1 and 2 drop out dorsally indicating senescence; tubercles and peripodia are well preserved. A highly specialized species. Drawings, Plate 59, figs. 1-3.

Melonechinus giganteus (Jackson).

Page 389.

- Fig. 2. Mississippi Group, Lower Carboniferous, Cumberland Gap, Tennessee. U. S. Nat. Mus. Coll., 39,909. Natural size. (This is the holotype of *Melonites granulatus* Troost, which with present evidence is not distinguishable from *giganteus*, and is here considered a synonym, p. 392). There are twelve columns of plates in an ambulacral area; the interambulacrum is incomplete, so that the number of columns is unknown, but a left adradial and five median columns are in place (p. 392). Drawing, Plate 59, fig. 4.

Melonechinus etheridgii (Keeping).

Page 385.

- Fig. 3. Lower Carboniferous Limestone, Clitheroe, Lancashire. (In regard to the locality of this specimen see p. 387.) Museum of Practical Geology Coll., London, 6,578, paratype. Natural size. There are six columns of plates in the left half-ambulacrum and also some plates of the right half-ambulacrum. Above the letter J are seen the two median columns of occluded plates which are relatively narrow for the genus and as in *M. keepingi* are not built up in melon-like ribs as they are in American species of the genus (pp. 359, 386). Six of the probably seven columns of plates are in place in the adjacent interambulacral area. Spines, tubercles, and peripodia are preserved in parts. Drawing, Plate 59, fig. 5.
- Fig. 4. Same horizon, Clitheroe, Lancashire. (In regard to the locality of this specimen see p. 387.) Museum of Practical Geology Coll., 6,577, holotype. Natural size. Part of Keeping's original slab, composed of more or less dissociated ambulacral areas and interambulacral plates. Drawing, Plate 59, fig. 6.

Melonechinus vanderbilti sp. nov.

Page 388.

- Fig. 5. Lower Carboniferous. Locality unknown, but probably from Tennessee. Vanderbilt University Coll., 220, holotype. Natural size. The specimen is a siliceous internal mold, or in part a siliceous pseudomorph of the plates. There are twelve columns of plates in an ambulacral area at the mid-zone and nine columns of plates in each of the five interambulacral areas. The numbers in white indicate the points of introduction of the several interambulacral columns. Drawings, Plate 61, figs. 1-4.

Figs. 1, 3, and 4 from photographs taken by J. W. Tutchter; fig. 2 by H. W. Tupper; fig. 5 by F. A. Saunderson.

Melonechinus keepingi sp. nov.

Page 384.

Figs. 1-3. Same specimen as photograph, Plate 58, fig. 1. Holotype.

- Fig. 1. Upper part of a test. $\times 2.7$. Ambulacrum with twelve columns of plates at the mid-zone; there are only two plates in the area dorsally, increasing passing ventrally to the full number of twelve columns at the mid-zone. (Compare text-fig. 237, p. 231.) Six columns of plates in the interambulacral area near the mid-zone, partly restored as indicated by dotted lines. The adambulacral columns 1 and 2 drop out dorsally, above which 3 and 4 become the adradial columns, a senescent character indicating an old-age individual.
- Fig. 2. Ambulacral plates, showing pore-pairs and tubercles. $\times 2.8$.
- Fig. 3. Interambulacral plates, showing tubercles. $\times 2.7$.

Melonechinus giganteus (Jackson).

Page 389.

- Fig. 4. Same specimen as photograph, Plate 58, fig. 2, (holotype of *M. granulatus* Troost, here considered a synonym). $\times 1.3$. Twelve columns of plates in an ambulacral area and six of the columns of interambulacrum A are in place; the rest are wanting on the right, but how many columns are absent is unknown (p. 392).

Melonechinus etheridgii (Keeping).

Page 385.

- Fig. 5. Same specimen as photograph, Plate 58, fig. 3. Paratype. $\times 0.9$. There are six columns of plates in the left half-ambulacrum, with also a few plates of the right half-ambulacrum. There are six columns of interambulacral plates in place and a seventh or adambulacral column is restored on the left of the figure as indicated by dotted lines (p. 387).
- Fig. 6. Same specimen as photograph, Plate 58, fig. 4. Holotype. $\times 1.4$. Part of a half-ambulacrum. The plates of the median occluded column *b* are only slightly wider than the plates of isolated columns (p. 386).
- Fig. 7. Lower Carboniferous Limestone, Frome, Somerset, England. British Mus. Coll., E 1,400. Ambulacral plates with pore-pairs and tubercles (p. 388). $\times 2.7$.
- Fig. 8. Lower Carboniferous, Coplaw, Clitheroe, Lancashire. Museum of Practical Geology Coll., 16,303. $\times 2.8$. Ambulacral plates seen from the interior, face of plates rounded inwardly, pores about in the middle of the plates instead of toward the next interambulacrum as on the exterior (p. 387).

Figs. 9-11. Lower Carboniferous Limestone, Frome, Somerset. British Mus. Coll., E 1,400. $\times 2.7$.

- Fig. 9. Interambulacral plate with tubercles and spines (p. 388).
- Fig. 10. Adradial plate with beveled adradial suture face (p. 388).
- Fig. 11. Adradial plate with facets for articulation with the ambulacral plates on the adradial face (p. 388).

Melonechinus giganteus (Jackson).

Page 389.

Figs. 12-15. Same specimen as photograph, Plate 60, fig. 3. Holotype (after Jackson, 1896, Plate 5, figs. 21-24).

- Fig. 12. Ambulacral detail from the right lower side of ambulacrum B (see photographic figure, Plate 60, fig. 3). $\times 2$. Only five columns of plates in a half-area are seen in this figure whereas six occur in a half-area at the ambitus, as seen in Plate 61, fig. 8. (Compare figs. 12 and 13 with text-fig. 237, p. 231.)
- Fig. 13. Ventral portion of the test. $\times 2$. Ambulacra have four columns of plates ventrally in each area; in the interambulacra the basicoronal row is wanting, but is restored in area A as indicated by dotted lines. There are three plates in the second row, four plates in the third row, and five plates in the fifth row.
- Fig. 14. Interambulacrum A. Natural size. The basicoronal row is wanting. In the first row preserved there are three plates, in the next row four plates; the columns 5, 6, and 7 originate very early, showing an accelerated development. Column 8 originates early; column 9 originates with a tetragonal plate against which are two heptagons, H', H'', to compensate for the two sides wanting. Above the tetragon is one row of eight plates, then column 9 begins again with a pentagonal plate, with a heptagon, H, on its right ventral border. This is a very exceptional anomaly (compare Plate 50, figs. 2, 3). Column 10 originates just below the mid-zone, and column 11 in the dorsal third of the area; column 11 drops out dorsally toward the apical disc, a senescent character (p. 391).
- Fig. 15. A single interambulacral plate with tubercles. $\times 4$.

Figs. 1-3, 5-11 drawn by A. T. Hollick; fig. 4 by J. Henry Blake; figs. 12-15 by J. H. Emerton.

PLATE 60.

Melonechinus multiporus (Norwood and Owen).

Page 375.

- Fig. 1. St. Louis Group, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll., 8,023 (from G. Hambach Coll.). Natural size. A quite typical adult specimen; melon-like ribs are rounded, moderately elevated; there are eight columns of plates in each interambulacral area; interambulacral plates are rhombic dorsally; ocular and genital plates are all in place. Genital G has three or perhaps four pores, all other genitals have three pores each. The apical disc measures proportionately 16% of the diameter of the test (pp. 376, 379, 384).
- Fig. 2. Same horizon and locality. F. Springer Coll., 8,108 (from G. Hambach Coll., K 8, the original of Miss Klem's, 1904, Plate 4, figs. 8a-8d). Natural size. Similar specimen to the above, but with nine columns of plates in each interambulacral area. Oculars are all insert. Genital E has three pores, genitals A and C apparently have four pores each, genital I is doubtful, and genital G has only two pores, a very unusual number. No pores seem to have been obliterated in this plate. The diameter of the apical disc measures proportionately about 16% of the diameter of the test (pp. 379, 384).

Melonechinus giganteus (Jackson).

Page 389.

- Fig. 3. Lower Carboniferous, Bowling Green, Kentucky. Mus. Comp. Zool. Coll., 2,989, holotype. Natural size. Ventral view. The specimen is a siliceous pseudomorph in fine condition of preservation and represents probably the largest known Palaeozoic echinoid. Melon-like ribs are strongly and sharply elevated. There are twelve columns of plates at the mid-zone in the ambulacral areas and eleven columns of plates above the mid-zone in each interambulacral area. The introduction of the columns of interambulacral plates can be plainly followed in several interambulacral areas, and is especially clear in area A. As seen imperfectly on the dorsal side of this specimen the apical disc measures about 15-16% of the diameter of the test. Drawings, Plate 59, figs. 12-15.

Figs. 1, 2, photographs by F. A. Saunderson; fig. 3 by C. H. Currier.

PLATE 61.

Melonechinus vanderbilti sp. nov.

Page 388.

Figs. 1-4. Same specimen as photograph, Plate 58, fig. 5. Holotype.

- Fig. 1. Section dorsal to the mid-zone. $\times 1.9$. A half-ambulacrum in surface view, and an interambulacrum drawn from the internal mold of the base of the plates. Six columns of plates in a half-area of an ambulacrum, and nine columns of plates in an interambulacral area. Ambulacral plates have tubercles and peripodia.
- Fig. 2. Interambulacrum A. $\times 0.9$. Drawn largely from an internal mold of the plates, but a few plates are in place as indicated by those having tubercles, partly restored ventrally and dorsally as indicated by dotted lines. There are three plates in the second row, four plates in the third row, column 5 originating in the seventh row. An exceptional pentagon, P, in the fifth row of column 5 has a compensating heptagonal plate, H, on its right side. Column 6 originates on the left of the center in the tenth row, column 7 in the 14th row, column 8 in the 20th row, and column 9 in the 29th row. Curiously, in both columns 8 and 9, there is an exceptional pentagon, P, with adjacent heptagons similar to that seen in column 5. Dorsally columns 1 and 2 drop out at the points X and columns 5 and 8 at the points P', P'', so that above this zone there are only five columns of plates in the area, indicating a senescent individual.
- Fig. 3. Surface detail. $\times 2.8$. Pore-pairs are in peripodia and lie toward the next adjacent interambulacrum in each plate; tubercles are represented on interambulacral plates.
- Fig. 4. Inner detail of an ambulacrum drawn from an internal mold. $\times 2.8$. Pore-pairs are in the middle of the plates of the inner columns of isolated plates, or toward the median line of the half-area in the lateral ambulacral column of demi-plates. Ambulacral plates are fan-shaped opposite the horizontal interambulacral sutures.

Melonechinus giganteus (Jackson).

Page 389.

Figs. 5-9. St. Louis Group, Lower Carboniferous, Clarksville, Tennessee. U. S. Nat. Mus. Coll., 42,340.

- Fig. 5. Detail of ambulacrum from the exterior. $\times 2.8$. Pore-pairs are in peripodia toward the adjacent interambulacrum in each plate, tubercles on interambulacral plates.
- Fig. 6. Same individual plates seen from the interior. $\times 2.7$. Pore-pairs of the median isolated columns are in the middle of each plate, but pore-pairs of the column of demi-plates bordering on the interambulacrum are in the inner border of each plate. Adambulacral plates are rounded on the adradial suture.
- Fig. 7. Profile view of plates shown in figs. 5 and 6. $\times 2.7$. The plates marked X and XX locate the individual plates of the several figures (pp. 360, 390).
- Fig. 8. Segment across a half-ambulacrum and completely across an interambulacrum, to show surface character. $\times 2.7$. There are six columns of plates in the right half-ambulacrum and eleven columns of interambulacral plates, the eleventh appearing in this view, which is about on the plane of the mid-zone. Peripodia are shown in ambulacral plates and tubercles on the same, and on a few interambulacral plates. (Compare text-fig. 237, p. 231.)
- Fig. 9. Segment showing structure viewed from the interior. $\times 2.7$. Pore-pairs are in the middle of all isolated ambulacral plates; but in the plates of the median (occluded) and lateral (demi-) columns the pore-pairs in each plate are toward the middle of the half-area. Ambulacral plates are fan-shaped opposite the horizontal interambulacral sutures (p. 60). (Compare Plate 56, fig. 5.)

PLATE 62.

Lepidechinus iowensis sp. nov.

Page 397.

- Fig. 1. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. F. Springer Coll., 8,010, holotype. Natural size. Five columns of moderately imbricating plates in two interambulacral areas and two columns of low plates in each ambulacral area. The ambulacral plates are seen best in area J. Drawings, Plate 63, figs. 3 and 4.

Lepidechinus tessellatus sp. nov.

Page 397.

- Fig. 2. Upper Burlington Limestone, Lower Carboniferous, Burlington, Iowa. Mus. Comp. Zoöl. Coll., 3,053, holotype. Natural size. Six columns of rounded hexagonal, moderately imbricating plates in each interambulacral area and two columns of low plates in each ambulacrum. Drawings, Plate 63, figs. 5 and 6.
- Fig. 3. Same horizon and locality. Mus. Comp. Zoöl. Coll., 3,054, paratype. $\times 2$. Specimen seen from the interior; ambulacra are wider than on the exterior, six columns of plates in each interambulacral area, and the plates are more sharply hexagonal than on the exterior. Oculars fail to reach the periproct or are exsert, each bearing a pore, and each ocular plate adorally covers an ambulacrum and laterally an interambulacrum in part on each side. Genitals with a single pore in the middle of the plates, a character seen in no other Palaeozoic type (pp. 171, 221). Drawings, Plate 63, figs. 7, 8.
- Fig. 4. Same horizon and locality. F. Springer Coll., 8,011, paratype. Natural size. Six columns of moderately imbricating plates in the interambulacral area and two columns of low plates in each ambulacral area. Drawings, Plate 63, figs. 9-11.

Lepidechinus imbricatus Hall.

Page 399.

- Fig. 5. Burlington Limestone, Lower Carboniferous, Burlington, Iowa. Mus. Comp. Zoöl. Coll., 3,055, holotype. $\times 2$. In each ambulacral area there are two columns of low plates imbricating strongly adorally. In each of the interambulacral areas A and I there are eight columns of plates imbricating strongly aborally and from the center laterally. Drawing, Plate 64, fig. 1.

Perischodomus biserialis M'Coy.

Page 401.

- Fig. 6. Lower Carboniferous, Ireland, probably from Hook Head. Trinity College Coll., Dublin. Natural size. Internal view of the ventral area. Ambulacral plates are wide and imbricate aborally and bevel over the interambulacrals laterally. Interambulacral plates imbricate adorally and toward the center. (All this direction of beveling is just the reverse of what is seen on the exterior because it is an internal view. Compare text-figs. 32-34, p. 75.) The primordial interambulacral plates are in the basicoronal row; there are two plates in the second row and three plates in the third row, as seen best in areas A and G. The fourth and fifth columns originate in succeeding rows. In area J a few ambulacral plates of the peristome are seen extending beyond the primordial interambulacral plate of area A, compare Plate 23, fig. 1 (p. 404). Drawing, Plate 64, fig. 2.
- Fig. 7. Same horizon and locality. Trinity College Coll., Dublin. Natural size. External view of the dorsal side. Two columns of low narrow plates in each ambulacral area, imbricating adorally and beveling under the adambulacrals. Five columns of plates in each interambulacral area near the mid-zone, the plates imbricating adorally and from the center laterally and over the ambulacrals. Two of the median columns drop out, passing dorsally in each area. Eccentric primary tubercles are seen on adradial and some other interambulacral plates (p. 404). Drawings, Plate 64, figs. 3-6.

Figs. 1 and 4 from photographs by F. A. Saunderson; figs. 2, 3, and 5 by H. W. Tupper; figs. 6 and 7 from photographs taken by A. C. Bridle in Dublin.

PLATE 63.

Lepidechinus irregularis (Keeping).

Page 396.

Figs. 1, 2. Lower Carboniferous Limestone, Hook Head, County Wexford, Ireland (after Keeping, 1876, Plate 3, figs. 6 and 7). Holotype in Sedgwick Museum, Cambridge, England, no. 12.

- Fig. 1. A small species with four or five columns of moderately imbricate plates in an interambulacral area; ambulacra narrow. $\times 0.9$.
 Fig. 2. Enlargement of an ambulacrum and interambulacrum. Ambulacral plates are low and narrow; pore-pairs uniserial; interambulacrum with four columns and a trace of a fifth column as represented by one plate dorsally; plates are rounded hexagonal, imbricating moderately dorsally and from the center laterally.

Lepidechinus iowensis sp. nov.

Page 397.

- Fig. 3. Same specimen as photograph, Plate 62, fig. 1. Holotype. $\times 1.8$. Ambulacral plates are low and narrow, with two columns in each area; pore-pairs uniserial. Interambulacra in each area with five columns of rounded hexagonal plates imbricating moderately dorsally and from the center laterally and over the ambulacra. Tubercles are all secondaries, uniform in size. A dorsal view of a lantern in place shows pyramids, braces, and teeth, which last are strongly inclined, indicating a flaring lantern as in *Archaeocidaris*.
 Fig. 4. The same. $\times 3.5$. Section looking ventrally to show the beveling of ambulacral and interambulacral plates, the latter shaded for contrast.

Lepidechinus tessellatus sp. nov.

Page 397.

- Fig. 5. Same specimen as photograph, Plate 62, fig. 2. Holotype. $\times 1.8$. Two columns of low plates in each ambulacral area, imbricating moderately ventrally; six columns of rounded hexagonal median or pentagonal adradial plates in each interambulacral area. Interambulacral plates imbricating moderately dorsally and from the center laterally and over the ambulacra.
 Fig. 6. Same specimen. $\times 3.4$. Ambulacral detail enlarged, from the area marked X in fig. 5.
 Fig. 7. Same specimen as photograph, Plate 62, fig. 3. Paratype. $\times 1.7$. Seen from the interior. The ambulacra are wider than on the exterior. Six columns of plates in each interambulacral area and the plates are more sharply hexagonal than on the exterior. Oculars each have one pore, and are exsert, an unusual Palaeozoic character (pp. 89, 221); each ocular plate adorally covers an ambulacrum and laterally in part an interambulacrum on either side (p. 52). Each genital plate has a single pore in the middle of the plate, a feature which I have seen in no other Palaeozoic type (pp. 171, 221).
 Fig. 8. Same specimen. Ocular and genital plates more enlarged. $\times 7$.
 Fig. 9. Same specimen as photograph, Plate 62, fig. 4. Paratype. $\times 1.8$. Six columns of moderately imbricating plates in interambulacrum A; tubercles shown in one plate of area C.
 Fig. 10. The same specimen, enlarged to show an interambulacral plate beveling over an ambulacral on the adradial suture. The interambulacral plate shaded.
 Fig. 11. The same specimen to show the imbricate edges of an interambulacral plate.

Figs. 1 and 2 copied by W. M. Barrows, all others drawn by J. Henry Blake.

PLATE 64.

Lepidechinus imbricatus Hall.

Page 399

- Fig. 1. Same specimen as photograph, Plate 62, fig. 5. Holotype. $\times 2.7$. Two columns of low plates in each ambulacral area, imbricating strongly ventrally. Eight columns of plates in the interambulacral areas A and I, the plates imbricating strongly dorsally and from the center laterally and over the ambulacra. There is a single plate in the basicoronal row, two plates in the second row, and thence increasing dorsally to the full number of plates and columns at the mid-zone. In area C, the introduction of columns ventrally is clear, but only seven columns can be counted in this area. Probably an eighth column would have appeared aborally in the part which is wanting.

Perischodomus biserialis M'Coy.

Page 401.

- Fig. 2. Same specimen as photograph, Plate 62, fig. 6. $\times 1.8$. Internal view of the ventral side. Ambulacral plates are broad, imbricating (in this view) dorsally and from the center laterally and over the adradials. Interambulacral plates imbricate ventrally and toward the center of the area as it is an internal view. (Compare text-figs. 32-38, p. 75, for imbrication seen from the exterior and interior.) The primordial interambulacral plates are in the basicoronal row, there are two plates in the second row, three plates in the third row, four plates in the fourth row, and five plates in the fifth row. In area G two interambulacral plates from the dorsal side are in place, seen from the exterior, but flattened down on to the ventral part of the test (compare Plate 74, fig. 2). This figure is in part restored as indicated by dotted lines (p. 404). (Compare text-fig. 30, p. 70.)
- Fig. 3. Same specimen as photograph, Plate 62, fig. 7. $\times 1.9$. Ambulacra are narrow, the plates low, the interambulacra near the mid-zone each with five columns of rounded plates which imbricate strongly dorsally and from the center laterally and over the ambulacra. Two of the columns, 3 and 4, drop out, passing dorsally in each area. An eccentric primary tubercle is on each adradial plate; similar tubercles occur on some plates of median interambulacral columns as shown in the photograph, but they were overlooked in making the drawing (p. 404).
- Fig. 4. The same from an area near the mid-zone. $\times 3.6$. Some ambulacral plates are pinched off so that they do not reach across the half-area.
- Fig. 5. The same. $\times 3.6$. Ambulacral plates near the apical disc, all crossing the half-area, pore-pairs uniserial.
- Fig. 6. The same enlarged. Ambulacral plates near the mid-zone alternately moderately wedge-shaped, strongly beveled under the adradials.
- Figs. 7, 8. Lower Carboniferous, Hook Head, County Wexford, Ireland. Sedgwick Museum Coll., Cambridge, England, (after Keeping, 1876, Plate 3, figs. 1 and 4). Cotype.
- Fig. 7. $\times 0.9$. Five columns of plates in each of the three most complete interambulacral areas, two areas are imperfect. There are eccentric primary tubercles on adradial plates and also on some of the plates of the median interambulacral columns.
- Fig. 8. Apical disc and part of the corona. $\times 1.8$. There are five genital plates and one small ocular in place. Genital plates have numerous pores. The apical disc is small proportionately to the diameter of the test. Eccentric primary tubercles are shown on several interambulacral plates and the same with secondary tubercles on one plate (p. 403).

Fig. 1 drawn from nature; figs. 2-6 from my sketches by J. Henry Blake; figs. 7 and 8 copied by W. M. Barrows.

PLATE 65.

Perischocidaris harteiana (Baily).

Page 408.

- Fig. 1. Lower Carboniferous, west shore of Lough Esk, about six miles from Donegal, Ireland. Trinity College Coll., Dublin. Holotype. Natural size. The specimen is an external sandstone mold. Six columns of plates in each ambulacral area at the mid-zone. Five columns of plates in each interambulacral area near the mid-zone, decreasing in the number of columns dorsally. Genitals and oculars all in place. Drawings, Plate 67, figs. 1-3. On the left in the figure is seen an impression of a second fragmentary specimen.
- Fig. 2. Plaster cast of same. Natural size. As this is a replica of the original specimen, the lettering is reversed from that of the sandstone mold (fig. 1).

Proterocidaris giganteus Koninek.

Page 410.

- Fig. 3. Lower Carboniferous, Dinant, Belgium (after Fraipont, 1904, Plate 4, fig. 2, where it is called *Oligoporus soreili* sp. nov., here considered a synonym). Natural size. This specimen represents a curious condition of preservation in which most of the test is intact and viewed from the dorsal side, but one interambulacrum I and two adjacent half-ambulacra H and J, are spread out (like peeling down a segment of an orange) and viewed from the interior. Four columns of plates in an ambulacral area; a half-area with two columns of plates is seen from the interior in area J. Eleven columns of interambulacral plates are seen at the mid-zone as viewed from the interior in interambulacrum I; but on the right-hand side of the area a twelfth column appears a little dorsal to the mid-zone. In area I, which is seen from the interior, the plates imbricate adorally and toward the center, largely covering the central column. In other areas seen from the exterior, the interambulacral plates imbricate aborally, and from the center laterally. Plates with tubercles and spines. (In the figure the two letters A in white, are from Fraipont's original photograph and signify ambulacral areas.) Drawings, Plate 67, figs. 6 and 7.

Figs. 1 and 2 from photographs taken by A. C. Bridle in Dublin; fig. 3 copied by F. A. Saunderman.

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Lepidesthes wortheni Jackson.

Page 416.

Figs. 1, 2. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana.

- Fig. 1. F. Braun Coll. An exceptionally clear specimen. Natural size. Eight columns of regular hexagonal plates in each ambulacral area, pore-pairs in the upper part of each plate, toward the next adjacent interambulacrum in each half-area. Three columns of plates at the mid-zone in each interambulacrum, all imbricating dorsally and from the center laterally and over the ambulacra. The median column, as usual in the species consists of wider plates which imbricate laterally in two directions, right and left, over the two adradial columns (compare *Lepidesthes colletti*, Plate 71, fig. 1; *Meekichinus elegans*, Plate 76, fig. 1). Where plates are wanting in interambulacrum A, the beveled edges show clearly. Drawing, Plate 67, fig. 8.
- Fig. 2. Mus. Comp. Zool. Coll., 3,171 (from R. T. J. Coll.). Natural size. Specimen smaller than fig. 1. Ambulacral plates are hexagonal in form. Interambulacrum A is nearly complete; tubercles very clear. Drawing, Plate 67, fig. 10.
- Fig. 3. No original label, but probably from the Keokuk Group of Crawfordsville, or that vicinity. Boston Soc. Nat. Hist. Coll., 11,601, holotype. A small individual. Natural size. Ambulacral plates are more rhombic in form than in figs. 1 and 2. Interambulacrum C shows four columns of plates ventrally as a character in development. Drawings, Plate 67, figs. 9 and 12.

Lepidesthes formosa Miller.

Page 418.

Figs. 4-7. Kaskaskia Group, Lower Carboniferous, Pulaski County, Kentucky.

- Fig. 4. Chicago Univ. Coll., 6,604, holotype. Natural size.
- Fig. 5. Same specimen. $\times 1.7$. Oriented by the Lovén method as the madreporite is preserved. Eight columns of plates in an ambulacral area and five columns of plates in each of the interambulacral areas at the mid-zone. Some ocular, genital, and periproctal plates are preserved. A madreporite with fine pores is clearly seen. Drawings, Plate 68, figs. 4-7.
- Fig. 6. Chicago Univ. Coll., 6,604, paratype. Natural size. Another specimen although with the same catalogue number, with parts of the lantern in place. Drawings, Plate 68, figs. 8 and 9.
- Fig. 7. F. Springer Coll., 8,042. Enlarged. $\times 2$. A very complete specimen for the ventral region. Teeth and pyramids are in the oral area, with ambulacral plates alone on the peristome. Eight columns of plates in each ambulacral area and four columns of plates in each interambulacral area as far dorsally as they are preserved. Drawing, Plate 68, fig. 3.

Lepidesthes coreyi Meek and Worthen.

Page 423.

- Fig. 8. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana. F. Braun Coll. Natural size. The ambitus is above the mid-zone (p. 32). There are ten to twelve columns of plates in each ambulacral area and six columns of plates in each of the interambulacral areas at the mid-zone. A very large and complete specimen. Drawings, Plate 68, figs. 18-20.
- Fig. 9. Same horizon and locality. Univ. of Michigan Coll., 149, holotype. Natural size. Quite complete from the ventral border to the mid-zone, but in part wanting dorsally. Ten columns of plates in each ambulacral area and six columns of plates in each interambulacral area at the mid-zone. Interambulacral plates imbricate strongly dorsally and from the center laterally and over the ambulaera.
- Fig. 10. The same specimen (after Meek and Worthen, 1873, Plate 16, fig. 2). Natural size. Outline restored dorsally as conceived by the authors; an interambulacral plate with secondary tubercles enlarged.

Lepidesthes carinata sp. nov.

Page 424.

- Fig. 11. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana. Mus. Comp. Zool. Coll., 3,175 (from R. T. J. Coll.), holotype. Natural size. Strongly elevated melon-like ambulacral areas, twelve columns of plates in an ambulacral area and six columns of plates in the interambulacral areas at the mid-zone as far as ascertained, but the details for most parts are obscure.

Perischodomus harteiana (Bailey).

Page 408.

Figs. 1-3. Same specimen as photographs, Plate 65, figs. 1 and 2. Holotype.

- Fig. 1. From near the mid-zone. Drawn from the original mold; therefore the lettering is reversed. $\times$ about 3. Three columns of ambulacral plates in a half-area.
- Fig. 2. Interambulacrum drawn from a plaster cast of the original mold. $\times$ 1.1. Five columns of plates near the mid-zone; columns 5, 4, and 3 drop out dorsally.
- Fig. 3. Drawn from a plaster cast of the original mold. $\times$ 1.4. Oculars insert, four genitals with three, five, or six pores each. No pores visible in genital E. Interambulacrum in contact with the oculars laterally.

Proterocidaris giganteus Koninck.

Page 410.

Figs. 4-7. Lower Carboniferous, Dinant, Belgium. Drawn from Fraipont's, 1904, photographic figures of what he calls *Oligoporus sorelli* sp. nov., here considered a synonym.

- Fig. 4. Segment of interambulacrum from mid-zone, seen from the exterior, adapted from Fraipont, 1904, Plate 5, fig. 1. $\times$ 0.9. There are 13 columns of interambulacral plates, the 13th originates on the left; an adjacent adradial plate, X, has six instead of five sides as is usual. Small primary with secondary tubercles.
- Fig. 5. Segment of an interambulacrum and anibulacrum, a little above the mid-zone, adapted from Fraipont's, 1904, Plate 5, fig. 2 (orientation reversed from his figure). $\times$ 0.9. Internal view. Four columns of plates in an ambulacral area (in B the plates are mechanically separated in the median line); pore-pairs in the middle of half-areas. Twelve columns of interambulacral plates, the twelfth originating on the left (right as seen from exterior).
- Fig. 6. Same specimen as photograph, Plate 65, fig. 3. $\times$ 0.9. From interambulacrum I to show imbrication as seen from interior; plates bevel adorally and toward the center and over plates of column 9. (Compare Plate 19, fig. 1.)
- Fig. 7. The same specimen. Interambulacral plates showing small primary and secondary spines. $\times$ 1.9.

Lepidesthes wortheni Jackson.

Page 416.

Figs. 8, 10, 11, 13, 14. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana.

- Fig. 8. Same specimen as photograph, Plate 66, fig. 1. $\times$ 1.8. In each ambulacral area there are eight columns of regular hexagonal plates at the mid-zone; pore-pairs in the upper part of each plate nearest the next adjacent interambulacrum; occluded columns are strongly defined as the pore-pairs are in outer sides of contiguous plates. Interambulacra with three columns of plates at mid-zone. In area A there are three plates in the lowest row seen, in the next row four plates; the fourth column is represented by only four plates, above which there are three columns only. Beveling seen clearly in area A where plates are wanting; secondary tubercles only.
- Fig. 9. Same specimen as photograph, Plate 66, fig. 3 (after Jackson, 1896, Plate 9, fig. 53). Holotype. $\times$ 1.8. Four columns of interambulacral plates are seen ventrally in area C and imperfectly in area A, above which there are three columns only. Ambulacral plates are more rhombic at the mid-zone than in figs. 8 and 10.
- Fig. 10. Same specimen as photograph, Plate 66, fig. 2. Ambulacral detail. $\times$ 3.6. Ambulacral plates rhombic in form. Pore-pairs in peripodia in the upper left part of each plate in the left half-area and in the upper right part of each plate in the right half-area. Tubercles are similar to those of the interambulacrum.
- Fig. 11. Section at the ambitus to show the beveling of plates, ambulacral plates are shaded. $\times$ 1.8.
- Fig. 12. Portion of lantern from reverse side of same specimen as photograph, Plate 66, fig. 3. Holotype. $\times$ 2.5. Left and right half-pyramids, foramen magnum shallow; the left epiphysis in place, but the right epiphysis is wanting.
- Fig. 13. Yale Mus. Coll., 319. Spines. $\times$ 3.
- Fig. 14. The same specimen, spine enlarged. $\times$ 14. Acicular, swollen at the base, with fine vertical striae.

Lepidesthes laevis Trautschold.

Page 418.

- Fig. 15. Lower Carboniferous, Moscow, Russia. Museum für Naturkunde Coll., Berlin. $\times$ 2.4. Seen from the exterior, showing four of the ambulacral and two interambulacral columns. Pore-pairs are in the upper part of plates. Interambulacral plates rounded, imbricating dorsally and laterally; a few tubercles are in place.
- Fig. 16. Same specimen seen from the interior. $\times$ 2.4. Pore-pairs are in the lower part of plates, interambulacral plates hexagonal, not rounded as on the exterior. (Compare text-figs. 32-34, p. 75.)
- Figs 17, 18. Lower Carboniferous, Miatschkowa, Province of Moscow, Russia (after Trautschold, 1879, p. 8; the orientation reversed from Trautschold's). Cotypes. Enlarged from Trautschold's original figures. $\times$ 1.7.
- Fig. 17. Three of the ambulacral with four interambulacral columns. Interambulacral plates rounded, imbricating.
- Fig. 18. Specimen with ambulacral plates on each side of the interambulacrum; four columns of interambulacral plates.
- Fig. 9 drawn by J. H. Emerton; figs. 1-3, 15, and 16 from my sketches; figs. 4-7 from Fraipont's photographic figures, figs. 17 and 18 after Trautschold; figs. 8 and 10-14 from nature by J. Henry Blake.

PLATE 68.

Lepidesthes laevis Trautschold.

Page 418.

- Fig. 1. Lower Carboniferous, Moscow, Russia. Museum für Naturkunde, Berlin. $\times 1.2$. Six columns of ambulaeral plates and a section showing adoral imbrication of same.
Fig. 2. Same specimen, one ambulaeral plate enlarged.

Lepidesthes formosa Miller.

Page 418.

Figs. 3-14. Kaskaskia Group, Lower Carboniferous, Pulaski County, Kentucky.

- Fig. 3. Same specimen as photograph, Plate 66, fig. 7. $\times 4.8$. Orally teeth and pyramids are in place. Ambulaeral plates only on the peristome. Four columns of ambulaeral plates in area B ventrally, increasing to eight columns aborally; all imbricate ventrally. Primordial interambulaeral plates in the basicoronal row, two plates in the second, three in the third, and four in the fourth row. Interambulaeral plates imbricate dorsally and laterally.
Figs. 4-7. Univ. of Chicago Mus. Coll. Same specimen as photographs, Plate 66, figs. 4 and 5. Holotype.
Fig. 4. Segment at the mid-zone. $\times 4.8$. Eight columns of plates in each ambulaeral area and five columns of plates in each interambulaeral area.
Fig. 5. Dorsal portion of test. $\times 4.6$. Ambulacra with one or two plates next the oculars, increasing in number passing ventrally. Interambulaeral columns all extend to the apical disc, young plates being in contact with the oculars. Oculars (shaded) are all insert with two pores, a remarkable feature (pp. 89, 413). Madreporite with two genital and madreporic pores (p. 172). Genitals 1 and 5 have three pores each. Periproct with angular, thin plates.
Fig. 6. Section at mid-zone. $\times 4.6$. To show beveling of interambulaeral plates; ambulaeral plates shaded.
Fig. 7. Isolated ambulaeral plate, to show the dorsal and ventral bevel. $\times 4.6$.

Figs. 8, 9. Chicago Univ. Coll., 6,604. Same specimen as photograph, Plate 66, fig. 6. Paratype.

- Fig. 8. Genital plate, with three pores. $\times 2.4$.
Fig. 9. Two pyramids. $\times 2.3$. In *b*, tooth in place, seen from exterior; in *a*, the tooth, seen from the interior, is grooved.

Figs. 10-15. Sloan's Valley, Pulaski County, Kentucky. F. Springer Coll.

- Fig. 10. Springer Coll., 8,023. Pyramid, with tooth in place, restored ventrally, as indicated by dotted lines. $\times 2.3$. Epiphyses wanting; foramen shallow. The inner aspect and section of the tooth are drawn from another specimen, which is in the Springer Coll., 8,023.
Fig. 11. Springer Coll., 8,027. Upper part of a left and right half-pyramid with epiphyses in place. $\times 2.2$.
Fig. 12. Springer Coll., 8,033. Pyramid, in side view, with ridges for the attachment of the interpyramidal muscle and an epiphysis, showing the tubercle, *tu.*, and glenoid cavity, *gl.*, for articulation with the brace. $\times 4.7$. (Compare Plate 2, fig. 7.)
Fig. 13. Springer Coll., 8,043. Brace, with epiphyses, the latter restored, as indicated by dotted lines. $\times 4.7$.
Fig. 14. The same specimen, face view, showing the brace resting against the epiphysis of the right half-pyramid, but the epiphysis is wanting in the left half-pyramid. $\times 4.6$.

Lepidesthes devonicans Whidborne.

Page 420.

- Figs. 15-17. Devonian, Pilton Beds, North Devon (after Whidborne, 1898, Plate 25, figs. 3a, 3b, and 3e). Museum of Practical Geology Coll., London, 7,160, and 7,161, counterparts, holotype.
Fig. 15. From a wax cast of ambulaeral plates showing pore-pairs. $\times 3$.
Fig. 16. From a wax cast of interambulaeral plates, showing tubercles. $\times 3$.
Fig. 17. Spine. $\times 6$.

Lepidesthes coreyi Meek and Worthen.

Page 423.

Figs. 18-22. Keokuk Group, Lower Carboniferous, Crawfordsville, Indiana.

- Fig. 18. Same specimen as photograph, Plate 66, fig. 8. Segment at the mid-zone. $\times 2.3$. Ten columns of plates in the ambulaeral area and at this zone five columns of plates in the interambulaeral area.
Fig. 19. Same specimen. $\times 2.2$. Ambulaeral plates with tubercles and spines.
Fig. 20. Same specimen. $\times 2.4$. Interambulaeral plates with tubercles and spines.
Fig. 21. Yale Mus. Coll., 317. Spines tapering, swollen at the base, longitudinally finely striate. $\times 4.9$. From a very large specimen, about 75 mm. high.
Fig. 22. Freiburg, i. B., Museum. Enlarged. Base of the test with the lantern in place.

Figs. 1, 2, and 22 after my sketches; figs. 15-17 after Whidborne by W. M. Barrows; all others figs. by J. Henry Blake.

- Fig. 1. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. Mus. Comp. Zoöl. Coll., 3,178 (from R. T. J. Coll.). Enlarged $\times 1.6$. Height of the specimen 44 mm. through the axis III, 5. A very complete specimen, oriented by the presence of the madreporite with its typical pores. There are few plates in an ambulacral area dorsally near the apical disc but they increase to sixteen columns of plates in each ambulacral area at the mid-zone. Four columns of plates in each interambulacrum; oculars, genitals, and periproctal plates in place. The apical disc is small, measuring proportionately about 16 % of the diameter of the test. Drawings, text-fig. 251, p. 428; Plate 71, fig. 1 (p. 428).
- Fig. 2. Keokuk Group, Lower Carboniferous, Salem, Washington County, Indiana. Univ. of Chicago Coll., 6,340. This is the specimen figured by White, 1880a, Plate 40, figs. 2, 2a. Natural size. A small specimen, but it shows sixteen columns of plates in an ambulacral area above the mid-zone and four columns of plates in an interambulacral area (p. 428).
- Fig. 3. The same specimen, enlarged. $\times$ nearly 1.8.
- Fig. 4. Keokuk Group, Lower Carboniferous, Bono, Indiana. Univ. of Chicago Coll., 6,641. Natural size. Not distorted, and showing the typical elliptical form of this species, sixteen columns of plates in an ambulacral area and four columns of plates in each interambulacral area at the mid-zone. Ambulacral plates are narrow hexagons at the mid-zone. Drawing, Plate 70, fig. 2 (p. 428).
- Fig. 5. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. F. Braun Coll. Natural size. Small specimen partly embedded in the rock, very well preserved, shows periproctal plates dorsally. There are sixteen columns of plates in an ambulacral area and four columns of plates in each interambulacral area (p. 429).
- Fig. 6. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. Mus. Comp. Zoöl. Coll., 3,177 (from R. T. J. Coll.). Natural size. Specimen uncompressed, of natural shape; teeth are seen ventrally; details of the coronal plates are very complete, especially at the mid-zone and dorsally. Ambulacral plates at the mid-zone are rhombic in outline, whereas in the larger specimens, figs. 7 and 8, they are hexagonal in outline at the mid-zone. Drawing, Plate 70, fig. 1 (p. 429).
- Fig. 7. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. Mus. Comp. Zoöl. Coll., 3,176 (from R. T. J. Coll.). Enlarged $\times$ about 1.3. The specimen is very large, measuring 70 mm. in height. Details of the plates are very clear. Sixteen columns of plates in an ambulacral area and four columns of plates in an interambulacral area at the mid-zone, but in area A a fifth column is introduced 14 mm. below top of the specimen, the only case of a fifth column seen in the species. This specimen shows well the low hexagonal form of ambulacral plates at the mid-zone, which is characteristic of large individuals, but dorsally the plates are rhombic in form as are all the ambulacral plates of a younger individual. Drawings, Plate 70, figs. 3 and 4 (p. 429).
- Fig. 8. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. Mus. Comp. Zoöl. Coll., 3,179 (from R. T. J. Coll.). Natural size. A very large and perfect specimen measuring 70 mm. in height, details of the plates exceptionally clear. Sixteen columns of plates in an ambulacral area at the mid-zone, four columns of strongly imbricating plates in each interambulacral area. In this specimen, as well as in fig. 7, the ambulacral plates are hexagonal in form at the mid-zone, whereas in younger specimens, figs. 4-6, they are rhombic at the mid-zone. As a localized stage dorsally, however, in this large specimen the younger ambulacral plates dorsally are rhombic in form as a localized stage in development (p. 430).

PLATE 70.

Lepidesthes colletti White.

Page 425.

- Fig. 1. Same specimen as photograph, Plate 69, fig. 6. $\times 3.6$. A specimen of the natural shape with no distortion. Ambulacral plates are nearly rhombic throughout, with sixteen columns in an ambulacral area at the mid-zone. Four columns of plates in an interambulacral area imbricating strongly dorsally and from the center laterally, and over the ambulacra on the adradial suture; the plates of column 3, that imbricates both ways laterally, are much broader than are the plates of other interambulacral columns. Ambulacral plates are rhombic in form from the mid-zone up; ventrally separated ambulacral plates show a dorsal beveled edge. Teeth are in place ventrally (pp. 426, 429). (Compare text-figs. 32-38, p. 75.)
- Fig. 2. Same specimen as photograph, Plate 69, fig. 4. Segment at the mid-zone. $\times 3.6$. Ambulacral plates are more hexagonal than in fig. 1, but the dorsal ambulacral plates in this specimen are rhombic; pore-pairs are toward the next adjacent interambulacrum in each half-area (p. 428).
- Fig. 3. Same specimen as photograph, Plate 69, fig. 7. $\times 3.5$. A very large individual; showing a segment at the mid-zone of a right half-ambulacrum, with the right occluded column, a' , of the left half-ambulacrum. Ambulacral plates are strongly hexagonal in shape, being proportionately lower and wider than in small individuals (p. 429). (Compare text-figs. 14, p. 54 and 21, p. 59.)
- Fig. 4. Same specimen as Plate 69, fig. 7. $\times 3.5$. A very large individual, showing the introduction of column 5 dorsally within 14 mm. of the top of the specimen; also spines in place (pp. 426, 430).
- Fig. 5. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. F. Braun Coll. A large specimen showing four columns of interambulacral plates, and tubercles (p. 429). $\times 3.5$.

PLATE 71.

Lepidesthes colletti White.

Page 425.

Fig. 1. Same specimen as photograph, Plate 69, fig. 1. $\times 3.4$. A very completely preserved specimen, oriented by the Lovén method as the axes are known from the presence of the madreporite. Sixteen columns of ambulacral plates at the mid-zone as seen best in area III. Ambulacral plates are all nearly or quite rhombic in form as are the younger plates dorsally in very large specimens in which they are hexagonal at the mid-zone (Plate 69, fig. 7). There are but few ambulacral plates in a row in each area dorsally near the oculars, the number in the rows increasing passing ventrally to the full number at or near the mid-zone. Four columns of plates in each interambulacral area, strongly imbricating dorsally and from the center laterally and over the ambulacra. In areas 1, 2, 3, and 5, column 3 has the wider plates which imbricate laterally in two directions; but in area 4, column 4 has the wider plates. (See also Plate 69, fig. 4; Plate 70, figs. 1 and 2.) Dorsally, four oculars are in place, which are indicated by cross lines; adorally they cover the ambulaera and laterally the interambulaera in part on either side. Five genitals are in place; genital 5 has three pores, genital 1 has two pores, and genital 2 shows fine madreporic pores, but no genital pores; probably they are hidden under the adjacent plates, genitals 3 and 4 are partially hidden and do not show any pores. Periproctal plates are thin, rounded, and rather sealy. This dorsal area is shown more enlarged in text-fig. 251, p. 428 (pp. 34, 172, 174, 427, 428).

Lepidesthes extremis sp. nov.

Page 430.

Fig. 2. Same specimen as photograph, Plate 72, fig. 1. Holotype. $\times 1.7$. Internal siliceous mold of the ventral side so that the ambulacral pores are on the lower part of each plate. (Compare Plate 67, figs. 15 and 16, where in *Lepidesthes laevis* the same ambulacral plates are seen in external and internal views.) There are sixteen columns of plates in an ambulacral area near the mid-zone, as seen in areas B and H, but there are fewer columns of ambulacral plates in an area farther ventrally. There are four columns of plates in the four interambulaera preserved, and the same number is given in area E, which is restored as indicated by dotted lines. An impression of a powerful lantern exists ventrally. Dorsal view of part of the same specimen, text-fig. 252, p. 431.

PLATE 72.

Lepidesthes extremis sp. nov.

Page 430.

- Fig. 1. Putnam Hill Limestone, Carboniferous (Coal Measures), New Lexington, Perry County, Ohio, collected by Mr. Eber Hyde, who loaned the specimen, which is no. 524 of his collection. Holotype. Natural size. Internal siliceous mold of the ventral side. A large powerful species with 16 columns of plates in an ambulacral area at the mid-zone and four columns of plates in each interambulacral area; an impression of a powerful lantern ventrally. The largest and geologically the highest species of the genus. Drawing, Plate 71, fig. 2.
- Fig. 2. The same specimen, dorsal view, internal mold. Natural size. In area G are seen impressions of four columns of interambulacral plates between the ambulacral areas F and H. Pores in the ambulacral plates are marked by elevated siliceous plugs. Drawing, text-fig. 252, p. 431.

Lepidesthes caledonica sp. nov.

Page 432.

Figs. 3-10. Lower Carboniferous Limestone, Roseobie, Fifeshire, Scotland. All in the British Mus. Coll.

- Fig. 3. British Mus. Coll., E 10,710, holotype. Ambulacral plate, from a right column next to an interambulacrum as indicated by the beveling on the right, oriented by the dorsal bevel which is strongly marked. The pore-pair is in a faint peripodium, and secondary tubercles exist. $\times 10$.
- Fig. 4. Holotype, E 10,710. Another ambulacral plate, similar to fig. 3. $\times 10$.
- Fig. 5. Holotype, E 10,710. Interambulacral plate, showing beveling ventrally and secondary tubercles. $\times 10$.
- Fig. 6. Paratype, E 10,711. Another interambulacral plate, similar to fig. 5. $\times 10$.
- Fig. 7. Holotype, E 10,710. Spines. $\times 20$. They are tapering, swollen at the base, and longitudinally finely striate.
- Fig. 8. Paratype, E 10,712. Pyramid. $\times 3$. The pyramid is wide-angled, foramen magnum shallow, median suture plain.
- Fig. 9. Same specimen seen from within, part of a grooved tooth in place. $\times 3$.
- Fig. 10. Paratype, E 10,704. Another pyramid, side view, faintly showing ridges for the attachment of interpyramidal muscles. $\times 3$.

Pholidocidaris tenuis Tornquist.

Page 440.

- Fig. 11. Lower Carboniferous Limestone, Coplaw, Clitheroe, Lancashire. Museum of Practical Geology Coll., London, 16,304. $\times 2$. Large, rounded, strongly imbricating interambulacral plates with eccentric primary, and secondary tubercles. A small ambulacral plate on the left is partially hidden, and there is a large plate in the center of the figure, which is apparently an ambulacral, with two pores (possibly these supposed pores are mechanically worn pits in an interambulacral plate).

Melonechinus multiporus (Norwood and Owen).

Page 375.

- Fig. 12. Upper St. Louis Limestone, Lower Carboniferous, St. Louis, Missouri. F. Springer Coll., S,117 (from G. Hambach Coll., H 14). Described as the holotype of *Melonites irregularis* Hambach, here considered a synonym. Natural size. Very imperfectly preserved. Ten columns of plates in an ambulacrum at the mid-zone. In the interambulacra there are seven columns of plates at the mid-zone in three areas; the other interambulacral areas are only preserved ventrally where there are five columns as usual in most species of the genus at that area (p. 380). The orientation is reversed from that given by Hambach.

Figs. 1, 2, and 12 from photographs by F. A. Saunderson; figs. 3-11 drawn by G. C. Chubb.

PLATE 73.

Lepidesthes extremis sp. nov.

Page 430.

- Figs. 1, 2. Putnam Hill Limestone, Carboniferous (Coal Measures), New Lexington, Perry County, Ohio, collected by Eber Hyde, who loaned the specimen, which is no. 525 of his collection. Paratype. Siliceous external molds.
- Fig. 1. Interambulacral plates, rounded in outline with secondary tubercles occurring as pits in the matrix. $\times 5.3$.
- Fig. 2. Spines, slender and tapering. $\times 5.3$.

Pholidocidaris irregularis (Meek and Worthen).

Page 434.

- Fig. 3. Same specimen as photograph, Plate 75, fig. 1. $\times 1.8$. Dorsal view, a fine delicately built test; apparently with six columns of plates in an ambulacral area, as indicated by three columns of plates in the right half of area D. The ambulacral plates are all small. There are six columns of plates in each of the two interambulacral areas preserved; columns 5 or 6 drops out early passing dorsally. Of the interambulacra, the adambulacral plates are much the largest, each with a large eccentric perforate primary tubercle and secondary tubercles. The plates of the middle columns of the interambulacra have secondary tubercles only; all interambulacral plates are thin, scaly, rounded in outline and imbricating strongly dorsally and from the center laterally and over the ambulacrals. A genital plate in area A has ten genital pores, and next to it a small plate, probably an ocular, has two pores (p. 437).
- Fig. 4. Same specimen as photograph, Plate 75, fig. 2. $\times 1.8$. A very similar specimen to fig. 3. In interambulacral area A, there are six columns, while in C there are only five columns of interambulacral plates, and in G there are apparently only five, but in area I there are again six columns of plates. Two genital plates have numerous pores each. Ambulacral plates are all small (p. 436).
- Fig. 5. The same specimen, a small primary and a secondary spine. $\times 1.8$ (p. 435).
- Fig. 6. Keokuk Group, Lower Carboniferous, Warsaw, Illinois. Mus. Comp. Zool. Coll., 3,070. This is the holotype of *Pholidocidaris meeki* Jackson, here considered a synonym. $\times 0.9$. Ventral area, the only known specimen of the genus showing this area at all satisfactorily. Ambulacral plates are large, each with a central pore-pair. There are apparently six columns of ambulacral plates at the mid-zone in an area. In interambulacrum C the primordial interambulacral plate is in place in the basicoronal row; there are two plates in the second row and three in the third. The fourth column does not originate until the sixth row, which is exceptionally late for any Palaeozoic species; the fifth column originates in the seventh row and the sixth column in the eighth row. Interambulacrum A is confused and imperfectly preserved. There is a primary tubercle on all interambulacral plates ventrally, whereas dorsally (figs. 3, 4) primary tubercles occur only on adradial plates (p. 438).
- Fig. 7. The same specimen, from the area marked X in area C of fig. 1. $\times 1.8$. Ambulacral plates showing their relatively large size, ventral imbrication, central pore-pair in an elevated prominence, and interambulacral plates, which are scaly, rounded, imbricating dorsally and laterally (p. 438).

Pholidocidaris irregularis (Meek and Worthen).

Page 434.

Fig. 1. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. F. Braun Coll. $\times 1.8$. This specimen, while imperfect and fragmentary, is most instructive. It represents a radial segment of a test flattened and distorted; also part of the dorsal plates have been removed. As a result, we see the exterior of part of the plates of the dorsal area (unshaded) and the interior of a portion of the ventral area (shaded for contrast); also a fragment of the lantern. Ambulacral plates ventrally (shaded) are very large, about rhombic in form, with pore-pairs about in the middle of each plate. On the other hand, ambulacral plates dorsally are small, and judging from the lower part of area B, there are six columns in an area at the ambitus. The interambulacra are represented clearly only by dorsal plates, column 1 of area A, column 2 of area C, and columns 2, 4, and 6 of area E (compare Plate 73, fig. 3). The adambulacral plates are striking, much larger than those of the median columns, scale-like, rounded, imbricating strongly; each adambulacral plate bears a primary eccentric perforate tubercle, whereas there are no primary tubercles on the plates of median columns. Two genital plates, *g*, have each numerous pores. A fragment of the lantern shows imperfectly a brace, *b*, two epiphyses, *ep*., and part of a pyramid, *p* (p. 439).

Fig. 2. Keokuk Group, Lower Carboniferous, Keokuk, Iowa. F. Springer Coll., 8,015. $\times 0.9$. This specimen, like the last, is very fragmentary, showing part of the dorsal plates (not shaded), part of the ventral plates (shaded to differentiate them), and an imperfectly preserved lantern. The specimen when alive was probably 100 mm. or more in diameter. Ambulacral plates are confused and imperfect, the most obvious feature being that the dorsal plates are small, as in fig. 1. The ventral (shaded) interambulacral plates imbricate toward the center of the area, and adorally; this is because they are seen from the interior. The dorsal plates (unshaded) clearly imbricate dorsally and from the center outward (compare text-figs. 32-38, p. 75). Adambulacral plates bear each an eccentric perforate primary tubercle and they are much larger than are the plates of median interambulacral columns. Six columns of interambulacral plates can be made out with reasonable certainty in area E and with less clearness in other areas. The lantern is strongly inclined, as indicated by the angles of the teeth (compare Plate 27, fig. 5); the pyramids, *p*, are in place, also the teeth, *t*, and in three areas, D, F, and H, a small worn plate that is apparently the brace. Below the letters D and F primary spines occur (p. 440).

Figs. 3-7. Keokuk Limestone, Lower Carboniferous, near Burlington, Iowa. Univ. of Michigan Coll., 1,740, C. A. White, collector. $\times 1.8$ (p. 438).

Fig. 3. Adambulacral plate from column 1 (left side), showing an eccentric perforate primary tubercle with scrobiculate and secondary tubercles; the plate is rounded, scale-like in form, with lateral and ventral beveling and facets for articulation with neighboring plates.

Fig. 4. Adambulacral plate from column 2 (right side), otherwise similar to fig. 3.

Fig. 5. Small adambulacral plate from column 1 (left side), similar to fig. 1; probably from near the mid-zone.

Fig. 6. Right half-pyramid; showing a moderately deep foramen magnum and a suture for the epiphysis.

Fig. 7. Left half-pyramid seen from within, showing pyramidal suture, dental slide, moderately deep foramen, and a wide lateral wing.

Pholidocidaris sp.

Page 440.

Figs. 8-10. Kaskaskia Group, Lower Carboniferous, Pulaski County, Kentucky. F. Springer Coll., 8,047. $\times 5.4$. A small species or a young individual, of interest only from its occurrence in the horizon and locality.

Figs. 8, 9. Two ventral ambulacral plates; 8 seen from the exterior, and 9 from the interior.

Fig. 10. Genital plates, each with many pores.

Pholidocidaris acuaria (Whidborne).

Page 441.

Fig. 11. Upper Devonian, East of Barnstaple, England (after Whidborne, 1898, Plate 25, fig. 1b, the type of his genus *Protocidaris*, here considered a synonym of *Pholidocidaris*). Museum of Practical Geology Coll., London, 7,158, cotype. $\times 4.5$. Interambulacral plates rounded, thin and scaly, with eccentric perforate primary and secondary tubercles; primary and secondary spines in place.

Pholidocidaris tenuis Tornquist.

Page 440.

Figs. 12, 13. Lower Carboniferous, Hunsrück, Germany (after Tornquist, 1897, Plate 21, figs. 8 and 9, Plate 22, fig. 8). Cotypes.

Fig. 12. Interambulacral plate. $\times 0.9$; and enlarged $\times 5.4$. With an eccentric perforate primary and secondary tubercles.

Fig. 13. Spine. $\times 1.4$.

Figs. 11-13 copied by W. M. Barrows; all others drawn by J. Henry Blake.*

PLATE 75.

Pholidocidaris irregularis Meek and Worthen.

Page 434.

- Fig. 1. Keokuk Group, Lower Carboniferous, Keokuk, Iowa. F. Springer Coll., 8,017, young individual. Natural size. Six columns of plates in an ambulacral area and six columns of plates in each interambulacral area. The plates of the adambulacral columns are relatively very large, especially high; a genital plate occurs in area A (p. 437). Drawing, Plate 73, fig. 3.
- Fig. 2. Keokuk Group, Lower Carboniferous, Montgomery County, Indiana. F. Braun Coll. Another young individual. Natural size. Six columns of interambulacral plates in area A, five columns in area C; there are two genital plates dorsally (p. 436). Drawing, Plate 73, figs. 4 and 5.
- Figs. 3-5. Keokuk Group, Lower Carboniferous, Hamilton or Nauvoo, Illinois (after Meek and Worthen, 1873, Plate 15, figs. 9a, 9b, and 4c. Holotype (p. 436).
- Fig. 3. Portion of dorsal part of a test. Natural size. The orientation is reversed from that given by Meek and Worthen. Ambulacral plates are small. Interambulacral plates imbricate dorsally and from the center laterally and over the ambulaera; in area A there is one adradial column of large, high plates, each bearing an eccentric primary and secondary tubercles, with three median columns of plates, all much smaller and lower, and bearing secondary tubercles only; the right-hand columns of this area are wanting. In area C there are plates from a right adradial and from median columns, but the plates are displaced and confused. Minute plate-like bodies scattered in the ambulacral and interambulacral areas are apparently foreign matter.
- Fig. 4. Reverse side of the same specimen. Natural size. The ventral area, showing relatively large ambulacral plates with central pore-pairs, and relatively small interambulacral plates, with primary and secondary spines, all confusedly mixed.
- Fig. 5. One of the primary spines, restored as indicated in outline. $\times$ about 2.

Meekechinus elegans sp. nov.

Page 443.

Figs. 6-8. Eskridge Shales, at the base of the Permian, Grand Summit, Kansas. J. W. Beede, collector, Univ. of Kansas Coll.

- Fig. 6. Holotype. Natural size. The madreporite is in place so that the specimen is oriented by the Lovén system. There are 20 columns of low rhombic plates in an ambulacral area at the mid-zone, the highest number known in any sea-urchin. The number of columns in an area is progressively less as we pass dorsally to the apical disc. The interambulacra are narrow, composed in each area of three columns of similar, small, strongly imbricating plates, each typically with one small primary tubercle bounded by a scrobicule, and in addition, rather large secondary tubercles; two or more oculars and five genitals are in place, the latter each with two or more genital pores. The madreporite is very distinct with many fine pores. Drawings, Plate 76, figs. 1-4, and 6.
- Fig. 7. Another specimen, paratype, almost exactly like fig. 1, but not quite as perfectly preserved. Natural size. Partially worn away dorsally so that parts of the dorsal portion of eight of the half-pyramids of the lantern are seen. Primary and secondary spines are numerous and well preserved, and in addition, tridentate pedicellariae, the first of such structures known from the Palaeozoic. Drawings, Plate 76, figs. 5, 8, and 9.
- Fig. 8. A fragment of a test, paratype, with well preserved lantern; plates and spines well preserved. Natural size. Drawings, Plate 76, fig. 7.

Figs. 1-4, 6. Same specimen as photograph, Plate 75, fig. 6. Holotype.

- Fig. 1. Dorsal view of the test of this remarkable echinoid. $\times 2.7$. Ambulacra very broad, with 20 columns of plates in each area near the mid-zone, seen best in the right half of area IV, where ten plates may be counted from the center outward in a half-area. Ambulacral plates are all low, wide rhombs; pore-pairs are in peripodia in that portion of each plate nearest to the next adjacent interambulacrum. Ambulacral plates imbricate strongly ventrally and laterally bevel under the adambulacrals. Interambulacra very narrow, each composed of three columns of small plates, which are uniform in size, imbricating strongly dorsally and from the center laterally and over the ambulacra on the adradial suture. Each plate typically with a small primary and secondary tubercles; occasionally and without apparent rule, a plate of the middle column may fail to develop a larger tubercle. Three small oculars and five genitals are preserved; a large madreporite with fine pores and many small tubercles is a prominent feature (more enlarged in fig. 6).
- Fig. 2. Ambulacral plates from the mid-zone of area I, from the place marked X in fig. 1, showing ventral imbrication. $\times 5.3$. Pore-pairs are in peripodia in the left of the plate on the left of the median line and in the right portion of the plate on the right of the median line; there are small primary tubercles with a scrobicule and secondary tubercles on each plate, the only case of such a structure of ambulacral plates known in the Palaeozoic. Small primary and secondary spines are present.
- Fig. 3. Similar ambulacral plates, from the right half of the mid-dorsal region of area III from the place marked X in fig. 1. $\times 5.4$. The aboral beveled edges are very marked; two of the plates are seen from the interior, with pores in the middle of each plate instead of near the lateral border of plate, as on the exterior.
- Fig. 4. Segment of an interambulacrum, at the mid-zone of area 3 from the point marked X in fig. 1. $\times 5.2$. The plates of column 3 imbricate strongly dorsally and from the center laterally and over the ambulacrals on either side. A small perforate primary tubercle with scrobicule is in the center of each plate, with, in addition, rather large secondary tubercles. Three typical primary and a secondary spine are drawn separately.
- Fig. 5. Segment of interambulacrum. Same specimen as photograph, Plate 75, fig. 7, paratype. Drawn from a point halfway between the ambitus and the apical disc in area 2. All interambulacral plates imbricate strongly dorsally and from the center laterally and over the ambulacra on the adradial suture. The middle plate of the upper row has no primary tubercle as have the others.
- Fig. 6. Apical region. $\times 5.3$. The plates in some parts are disarranged, but in others are apparently in their original relation. Oculars II and III are in place, exsert, and small, but adorally cover the ambulacra and laterally the interambulacra in part on either side. Apparently there is an ocular, *oc.*, in area V, but one cannot ascertain an ocular with assurance in areas IV or I. The madreporite is very large, with numerous fine madreporic pores, and in addition two genital pores, also many secondary, but no primary tubercles. Genitals 1, 3, and 4 are small plates each with a primary and secondary tubercles and four genital pores; genital 5 is similar, but with three pores. The ambulacra dorsally have only one plate in contact with the ocular, but the absence of a second plate is probably due to displacement during fossilization in the slipping of strongly imbricating plates. A few plates in the center may be considered as periproctal.
- Fig. 7. Same specimen as photograph, Plate 75, fig. 8. Paratype. $\times 5.3$. A nearly complete lantern. Pyramids are wide-angled, with a rather deep foramen magnum, seen best in area E. In area A the side wing of the left half-pyramid shows ridges for the attachment of the interpyramidal muscle. In area C, a tooth is in place, seen for nearly its whole length on account of the accidental separation of the half-pyramids on their suture line. The tooth is vertically striate, and distally dentate, the same structure being seen also in the tooth of area A. The left half-pyramid of area E shows the suture line for the epiphysis which is wanting, but the right half-pyramid of C has the epiphysis, *ep.*, in place, against which lies a somewhat displaced brace, *b.* A bifid compass, *c.*, lies out of place below the pyramid E (p. 181).
- Figs. 8, 9. The same specimen as Plate 75, fig. 7. Paratype. Tridentate pedicellariae. $\times 62$. These are quite like the pedicellariae of modern Echini, and are the first recorded from the Palaeozoic and indeed are the first found fossil from any formation as far as I am aware excepting in the Jurassic *Pelanechinus* in which they are described by Groom (1887), (p. 61).

J. HENRY BLAKE DEL.

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