Porter M. Kier

Tertiary
and Mesozoic
Echinoids of
Saudi Arabia

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SMITHSONIAN CONTRIBUTIONS TO
PALEOBIOLOGY

NUMBER 10

Porter M. Kier Tertiary and Mesozoic
Echinoids of
Saudi Arabia

ISSUED

JUN 14 1972

SMITHSONIAN INSTITUTION PRESS
CITY OF WASHINGTON

1972

ABSTRACT

Kier, Porter M. Tertiary and Mesozoic Echinoids of Saudi Arabia. *Smithsonian Contributions to Paleobiology*, number 10, 242 pages, 50 figures, 67 plates, 1972.—The Mesozoic and Tertiary echinoids are described from Saudi Arabia. Fifty-one species, thirty-four of them new, occur in beds ranging from the Lower Jurassic to the Miocene. Two species are present in the Lower Jurassic (Toarcian) Marrat Formation, one is new: *Acrosalenia marratensis*. The Middle Jurassic (Bajocian-Bathonian) middle Dhurma Formation yielded eleven species, all new: *Acrosalenia arabica*, *Acrosalenia dhrumaensis*, *Heterosalenia dhrumaensis*, *Pseudocidaris depressa*, *Polycyphus arabicus*, *Pseudosalenia magniprocta*, *Farquharsonia crenulata*, *Leioechinus namus* (type species of new genus of the family Stomechinidae), *Plesiechinus altus*, *Bothryopneustes arabica*, and *Bothryopneustes dhrumaensis*. Thirteen species are described from the Late Jurassic (Callovian) upper Dhurma Formation, including twelve new species: *Acrosalenia bowersi*, *Pseudocidaris romani*, *Pseudocidaris raratuberculata*, *Hypodiadema nanituberculata*, *Heterosalenia brocki*, *Heterosalenia ornata*, *Leioechinus amplus*, *Polycyphus parvituberculatus*, *Holactypus phelani*, *Pygurus (Pygurus) arabicus*, *Bothryopneustes kauffmani*, and *Bothryopneustes inflata*. One species, *Bothryopneustes orientalis* Fourtau, occurs in the Callovian Tuwaiq Mountain Limestone. Eleven species are reported from the Late Cretaceous (Campanian or Maestrichtian) Aruma Formation, five of which are new. *Rhynchopygus arumaensis*, *Proraster granti*, *Iraniaster bowersi*, *Iraniaster affinemorgani*, and *Iraniaster affinidouvillei*. The sympatric pairing of two species of *Iraniaster* corresponds to a pairing of another two species of this genus in the Senonian of Iran. This pairing has been reported in living spatangoids. The Early Cretaceous Yamama Formation yielded the new species *Pygurus (Pygurus) yamamaensis*. Beds of Eocene or Oligocene age yielded three echinoid species, one of them new: *Agassizia arabica*. Nine species occur in the Miocene Dam Formation, three are new: *Schizechinus pentagonus*, *Fibularia damensis*, and *Agassizia powersi*. These Miocene echinoids are quite similar to species now living in the littoral zone.

The distribution and affinities of the echinoid species indicate faunal provinces in the Jurassic largely confined to Saudi Arabia, and in the Cretaceous confined to Saudi Arabia and Iran with some connections to North Africa but not to India. The Miocene distribution differs in being a part of a fauna occurring along the present borders of the Persian Gulf and the Arabian Sea of Saudi Arabia, Iran, West Pakistan, and northwestern India.

Official publication date is handstamped in a limited number of initial copies and is recorded in the Institution's annual report, Smithsonian Year.

UNITED STATES GOVERNMENT PRINTING OFFICE
WASHINGTON · 1972

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price \$3.00 (paper cover)
Stock Number 4700-0178

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Porter M. Kier

Tertiary and Mesozoic Echinoids of Saudi Arabia

Introduction

For many years I heard of remarkable echinoid faunas in Saudi Arabia. When I received a few specimens for identification from the Arabian-American Oil Company (Aramco) in 1961, I became very anxious to go to Saudi Arabia to collect. Mr. S. D. Bowers of Aramco initiated the correspondence and Mr. O. A. Seager made the necessary arrangements. In 1962 an expedition led by Dr. R. W. Powers was undertaken. This Smithsonian-Aramco expedition consisted of Dr. Erle G. Kauffman and myself from the Smithsonian Institution and Dr. R. W. Powers, Mr. C. D. Redmond, and Mr. H. A. McClure from Aramco. The Smithsonian members were flown into central Saudi Arabia in an Aramco aircraft where they joined the oil company party of geologists, and support personnel. We visited the classic Jurassic outcrops of the Jabal Tuwayq region and collected extensively from measured sections. Large collections were made of mollusks, brachiopods, sponges, corals, and echinoids, and with the guidance of the Aramco geologists, the stratigraphic positions of these collections were noted relative to prominent marker beds. Our party moved by truck convoy eastward and collected from sites in the Cretaceous and finally in the Tertiary. Dr. Kauffman made an extensive collection of mollusks which he is now studying, and it is hoped that the rest of the fauna will be studied soon. The ammonites from this expedition have been described by Imlay (1970).

This report is based on the echinoids collected on this expedition and all those collected earlier and

later by the Aramco geologists. The echinoids from the Yamama had been tentatively identified by Dr. Jean Roger.

Previous Work

With the exception of the ammonites, the Saudi Arabian megafossil fauna is largely unknown. The Jurassic ammonites have been described by Arkell (1952) and Imlay (1970) and one echinoid species has been described by R. V. Melville (1955). Aramco geologists and various consultants have tentatively identified many of the fossils, and these identifications are in Powers, Ramirez, Redmond, and Elberg (1966).

Methods

Generally, descriptions and illustrations of echinoid species are inadequate. It is nearly always necessary to borrow the type specimen in order to decide whether new material is conspecific. Thanks to modern computers some of these problems can now be overcome. Chesher (1968) has explained superbly why it is necessary to provide more statistical information on echinoid specimens. Where possible in this paper I have made the measurements of the spatangoids that he recommends.

The value of making measurements and statistically examining them was clearly demonstrated to me in my study herein of *Moiria adamthi* Clegg and *Laganum tumidum* Duncan and Sladen. These Miocene-Pliocene species are very similar to living species, and *L. tumidum* has been considered by two previous workers to be conspecific with the living *L. depressum* L. Agassiz. However, the results of the student t-test

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showed clearly that the species were distinct and that the chances that they could be the same were less than one in a thousand. Without this statistical support, I had intended to consider *L. tumidum* a synonym of *L. depressum*, and *Moiria adamthi* a very close ancestor of *M. atropos*.

Acknowledgments

I thank Dr. Erle G. Kauffman who accompanied me on the collecting trip to Saudi Arabia and who, with great energy and vigor, found many of the echinoids described herein. Furthermore, I am indebted to him for cheering me up during those desperate days when no echinoids were found. I thank the Arabian American Oil Company (Aramco), not only for providing all the echinoids collected by their geologists on previous expeditions, but also for arranging and supporting the 1962 collecting trip. Dr. R. W. Powers, Mr. C. D. Redmond, and Mr. H. A. McClure guided us on this trip and collected many specimens. Mr. S. D. Bowers provided much subsequently needed information. Dr. Ralph Imlay provided important data from his study of the ammonites, and Dr. Neil Roth of the Mathematician Information Systems Division of the Smithsonian Institution led me through the labyrinth of pitfalls and terrors of statistics and computers. Mr. Thomas F. Phelan did all the excellent photography, made many of the preparations, assisted in the computer programming, and performed many other tasks. The art work was done by Mr. Lawrence B. Isham, scientific illustrator of the Department of Paleobiology.

The following curators most kindly lent me specimens: Miss Ailsa M. Clark and Dr. R. P. S. Jefferies of the British Museum (Natural History); Dr. R. B. Rickards and Dr. Colin Forbes of the Sedgwick Museum, Cambridge, England; Dr. Ian Rolfe of the Hunterian Museum University, Glasgow, Scotland; Dr. Jean Roman of the Muséum National d'Histoire Naturelle, Paris; Dr. J. Manivit of the University D'Orsay, Centre d'Etudes et de Recherches de Paleontologie Biostratigraphique, France; Dr. K. N. Prasad of the Geological Survey of India, who very kindly obtained for me casts of some of Clegg's type specimens; Dr. Leo G. Hertlein of the California Academy of Sciences.

Also, I thank Dr. Richard E. Grant of the United States Geological Survey, Professor J. Wyatt Durham

of the University of California, Berkeley, Dr. Erle G. Kauffman of the Smithsonian Institution, and Mr. H. A. McClure, staff paleontologist of Aramco, who critically read the manuscript and made many useful suggestions. Mr. McClure, in particular, prepared the locality section besides making valuable suggestions throughout the manuscript. Dr. Richard H. Chesher of Westinghouse Research advised me on the living habits of some spatangoid echinoids.

Stratigraphy and Echinoid Faunas

Mesozoic and Tertiary strata crop out in a great curved belt in central Arabia. The stratigraphy of these formations has been described in detail in Powers, Ramirez, Redmond, and Elberg (1966), and a chart of the formations from that work is repeated herein as Figure 2 with ages, generalized lithologies, and thicknesses. Echinoids have been found only in the Lower Jurassic Marrat Formation, Middle and Upper Jurassic Dhurma Formation, Upper Jurassic Tuwaiq Mountain Limestone, Lower Cretaceous (Valanginian) Yamama Formation, Upper Cretaceous Aruma Formation, unnamed Eocene-Oligocene beds, and the Miocene Dam Formation (Table 1).

The Jurassic collections made in the 1962 Smithsonian-Aramco expedition were made from measured sections selected by R. W. Powers. These Jurassic sections occur in a small area southeast of the city of Riyadh (Figure 1). The position within the section was located for each fossil collection within one-half meter. Each horizon was measured vertically (stratigraphically) from a well-known marker bed such as the Dhibi limestone of the lower Dhurma Formation. Many of the collections made earlier or later by the Aramco geologists also came from measured sections.

The Lower Cretaceous echinoids came from the vicinity just south of the town of Al Yamamah; Upper Cretaceous echinoids came from various localities scattered along the approximate northern extent of the Aruma plateau. Miocene collections came mostly from the northeast near-littoral area, excepting several localities from the extreme northwest corner of Saudi Arabia.

Lower Jurassic—Marrat Formation

The Marrat Formation was designated and published by Steineke and Bramkamp (1952). Particulars of

FIGURE 1.—Map of Saudi Arabia showing location of the Jurassic measured sections collected from by the Smithsonian-Aramco expedition of 1962. The location of the area of the upper geological map is indicated on the lower map by a small black rectangle southwest of Riyadh. After Imlay 1970 (emended).

Age			Formation	Generalized lithologic description	Thickness (Type or reference section)	Major stratigraphic divisions	
CENOZOIC	QUATERNARY AND TERTIARY		Surficial deposits	Gravel, sand, and silt			
	TERTIARY	Miocene and Pliocene	Kharj	Limestone, lacustrine limestone, gypsum, and gravel	28 m	Miocene and Pliocene Clastic Rocks	
			Hofuf	Sandy marl and sandy limestone; subordinate cal- careous sandstone. Local gravel beds in lower part	95 m		
			Dam *	Marl and shale; subordinate sandstone, chalky lime- stone, and coquina	91 m		
			Hadrukh	Calcareous, silty sandstone, sandy limestone; local chert	84 m		
	Eocene	Lutetian	Dammam	Limestone, dolomite, marl, and shale	33 m	Upper Cretaceous to Eocene Carbonate Rocks	
		Ypresian	Rus	Marl, chalky limestone, and gypsum; common chert and geodal quartz in lower part. Dominantly an- hydrite in subsurface	56 m		
		Thanetian Montian(?)	Umm er Radhuma	Limestone, dolomitic limestone, and dolomite	243 m		
	Paleo- cene	Possible discontinuity					
	MESOZOIC	CRETACEOUS	Maestrichtian	Aruma *	Limestone; subordinate dolomite and shale. Lower part grades to sandstone in northwestern and southern areas of outcrop	142 m	Middle Cretaceous Clastic Rocks
Campanian							
Turonian(?)			Wasia (Sakaka Sandstone of northwest Arabia)	Sandstone; subordinate shale, rare dolomite lenses	42 m	Late Lower Cretaceous Clastic Rocks	
Cenomanian			Biyadh	Sandstone; subordinate shale	425 m		
Aptian			Buwaib	Biogenic calcarenite and calcarenitic limestone inter- bedded with fine sandstone in upper part	18 m		
Barremian			Yamama *	Biogenic-pellet calcarenite; subordinate aphanitic limestone and biogenic calcarenitic limestone	46 m		
Hauterivian			Sulay	Chalky aphanitic limestone; rare biogenic calcarenite and calcarenite limestone	170 m		
Valanginian			Hith	Anhydrite	90 m	Upper Jurassic and early Lower Cretaceous Carbonate Rocks	
Berriasian		Arab	Calcarenite, calcarenitic and aphanitic limestone, dolomite and some anhydrite. Solution-collapse carbonate breccia on outcrop due to loss of inter- bedded anhydrite	124 m			
Tithonian							
JURASSIC		Kimmeridgian	Jubaila	Aphanitic limestone and dolomite; subordinate cal- careenite and calcarenitic limestone. Lower part sandstone between 20° N. and 22° N.	±118 m		Lower and Middle Jurassic Clastic and Carbonate Rocks
			Hanifa	Aphanitic limestone, calcarenitic limestone, and cal- careenite	113 m		
		Oxfordian	Tuwaiq Mountain *	Aphanitic limestone; subordinate calcarenitic lime- stone and calcarenite. Abundant corals and stroma- toporoids in upper part	203 m		
		Callovian					
		Callovian(?)	Dhurma *	Aphanitic limestone and shale; subordinate calcar- enite. Dominantly sandstone south of 22° N. and north of 26° N.	375 m		Permian and Triassic Clastic Rocks
		Bathonian	Marrat *	Shale and aphanitic limestone; subordinate sandstone	103 m		
		Bajocian	Minjur	Sandstone; some shale	315 m		
		Toarcian	Jilh	Sandstone, aphanitic limestone, and shale; subordi- nate gypsum	±326 m		
TRIASSIC		Lower	Sudair	Red and green shale	116 m		
PALEOZOIC		PER- MIAN	Upper	Khuff	Limestone and shale; dominantly sandstone south of 21°N.	171 m	Lower Paleozoic Clastic Rocks
	Lower		Wajid	Sandstone, gravel, and basement erratics (Recognized only in southwestern Saudi Arabia and northern Yemen)	950 m calculated		
	undated		Precambrian basement complex				
	DEVON- IAN	Lower	Jauf	Limestone, shale, and sandstone	299 m	Lower Paleozoic Clastic Rocks	
		Tabuk	Sandstone and shale	1,072 m			
	ORDO- VICIAN AND SI- LURIAN	Saq	Umm Sahm Ram Quweira Siq	Sandstone	+ 600 m		
	Precambrian basement complex						

Precambrian basement complex

the type section were published by Steineke, Bramkamp, and Sander (1958), and an additional reference section was designated and described by Powers, Ramirez, Redmond, and Elberg (1966). The formation consists of aphanitic and calcarenitic limestone, dolomites, siltstones and sandstones, but the echinoids were mainly collected from fine-grained limestones. The formation has been dated by ammonites as Toarcian (Arkell 1952). It is locally very fossiliferous containing also numerous brachiopods and mollusks. Although a large number of echinoids were collected, only two species are recognized: *Echinotiara arabica* Melville, and *Acrosalenia marratensis* Kier, new species. These species are confined to Saudi Arabia and therefore provide no further information as to the age of the Marrat.

Middle, Upper Jurassic—Dhruma Formation

Beds of the Dhruma Formation, with its apex near Riyadh, form an arc that extends a distance of more than 900 kilometers. The formation was formally named and type section designated in publication by Steineke, Bramkamp, and Sander (1958). A more detailed reference section was published by Powers, Ramirez, Redmond, and Elberg (1966). The outcrop belt is at its maximum 25 kilometers wide and the formation reaches a maximum thickness of 375 meters at the reference section. The echinoids collected in 1962 by the Smithsonian-Aramco party came from three measured sections (KK7, KK8, KK9) southwest of Riyadh (Figure 1) where the Dhruma is exposed in a steplike series of high limestone-capped scarps and broad dip slopes. The three sections were stratigraphically measured from the Dhibi limestone member which separates the lower and middle Dhruma, and therefore collections made from these sections can be related to each other stratigraphically. No echinoids were collected from the lower Dhruma but many were found in the middle and upper Dhruma. Because the fauna from the middle Dhruma is entirely different from that of the upper they are treated here separately.

FIGURE 2.—Saudi Arabian outcrop sequence. Copied directly from Powers, Ramirez, Redmond, and Elberg (1966, table 1, opposite page D6). Asterisks have been added to this section to show where the echinoids were collected. Three species were found in Eocene-Oligocene ? beds which are not indicated on this section.

MIDDLE DHRUMA FORMATION

Most of the echinoids came from calcarenitic and aphanitic limestones. Most specimens were weathered out on the surface, although some were collected from limestone still in place. Generally, the echinoids appeared to have weathered out very nearly in place, and only a few specimens were found which had obviously moved any great distance down slope. Eleven new species are described from the middle Dhruma. At least four more species are present, but not enough is known of these species to permit description because only fragments of them were found.

Acrosalenia arabica Kier, new species
Acrosalenia dhrumaensis Kier, new species
Heterosalenia dhrumaensis Kier, new species
Pseudocidaris depressa Kier, new species
Polycyphus arabica Kier, new species
Pseudosalenia magniprocta Kier, new species
Farquharsonia crenulata Kier, new species
Leioechinus namus Kier, new species
Plesioechinus altus Kier, new species
Bothryopneustes arabica Kier, new species
Bothryopneustes dhrumaensis Kier, new species

According to Imlay (1970:5) the lower few meters of the middle Dhruma are definitely of late Bajocian age because they contain the ammonite *Spiroceras bifurcatum* (Quenstedt). Imlay considers the rest of the middle Dhruma to be Bathonian also on the evidence of the ammonites. The echinoids are of little help in determining the age of the beds because all the species are new. The fauna, however, has its closest affinities with Bathonian and Callovian species. *Polycyphus arabicus* is very similar to *P. textilis* L. Agassiz from the late Bathonian and Callovian of France and Callovian of Madagascar, and *P. drayi* Fourtau from the Callovian of Egypt. *Heterosalenia dhrumaensis* resembles *H. alloiteau* Zoeke from the Middle Jurassic of Lebanon, and *Acrosalenia arabica* Kier resembles *A. humei* Fourtau from the Bathonian of Egypt.

Many of the species have a fairly wide stratigraphic range within the middle Dhruma (Figure 3) but only one species extends more than 112.5 meters above the Dhibi limestone member. *Bothryopneustes dhrumaensis* has the widest range of any of the species, extending from 32.5 to 161.5 meters above the Dhibi limestone.

TABLE 1.—*The stratigraphic distribution of the echinoids of Saudi Arabia.*

Species	JURASSIC				CRETACEOUS		CENOZOIC	
	TOAR- CIAN	BAJO- CIAN- BATHO- NIAN	CALLOVIAN	Tuwaiq Moun- tain Lime- stone	NEOCO- MIAN	CAMPA- NIAN- MAE- STRICH- TIAN	EOCENE- OLIGO- CENE?	MIOCENE
	Marrat Forma- tion	Middle Dhruma Forma- tion	Upper Dhruma Forma- tion		Yamana Forma- tion	Aruma Forma- tion		Dam Forma- tion
<i>Acrosalenia arabica</i> Kier, new species		X						
<i>A. bowersi</i> Kier, new species			X					
<i>A. dhrumaensis</i> Kier, new species		X						
<i>A. marratensis</i> Kier, new species	X							
<i>Actinophyma</i> cf. <i>A. spectabile</i> Cotteau & Gauthier						X		
<i>Agassizia</i> (<i>Agassizia</i>) <i>powersi</i> Kier, new species ..								X
<i>Agassizia</i> (<i>Anisaster</i>) <i>arabica</i> Kier, new species ..							X	
<i>Bothryopneustes arabica</i> Kier, new species		X						
<i>B. dhrumaensis</i> Kier, new species		X						
<i>B. inflata</i> Kier, new species			X					
<i>B. kauffmani</i> Kier, new species			X					
<i>B. orientalis</i> Fourtau				X				
<i>Brissus latidunensis</i> Clegg								X
<i>Coptodiscus nomiae</i> Cotteau & Gauthier						X		
<i>Echinodiscus desori</i> Duncan and Sladen								X
<i>E. ginauensis</i> Clegg							X	
<i>Echinotiara arabica</i> Melville	X							
<i>Eupatagus</i> sp.							X	
<i>Farquharsonia crenulata</i> Kier, new species		X						
<i>F. somaliensis</i> Currie			X					
<i>Fibularia damensis</i> Kier, new species								X
<i>Globator mortenseni</i> Checchia-Rispoli						X		
<i>Goniopygus superbus</i> Cotteau and Gauthier						X		
<i>Heterosalenia brocki</i> Kier, new species			X					
<i>H. dhrumaensis</i> Kier, new species		X						
<i>H. ornata</i> Kier, new species			X					
<i>Holactypus phelani</i> Kier, new species			X					
<i>Hypodiadema nanituberculata</i> Kier, new species ..			X					
<i>Iraniaster affinidouvillei</i> Kier, new species						X		
<i>I. affinemorgani</i> Kier, new species						X		
<i>I. bowersi</i> Kier, new species						X		
<i>Laganum tumidum</i> Duncan and Sladen								X
<i>Leioechinus amplus</i> Kier, new species			X					
<i>L. namus</i> Kier, new species		X						
<i>Lovenia</i> cf. <i>Lovenia elongata</i> (Gray)								X
<i>Moiria adamthi</i> Clegg								X
<i>Opechinus costatus</i> (D'Archiac and Haime)								X
<i>Plesiechinus altus</i> Kier, new species		X						

TABLE 1.—*The stratigraphic distribution of the echinoids of Saudi Arabia—Continued.*

Species	JURASSIC				CRETACEOUS		CENOZOIC	
	TOAR- CIAN	BAJO- CIAN- BATHO- NIAN	CALLOVIAN	Tuwaiq Moun- tain Lime- stone	NEOCO- MIAN	CAMP- NIAN- MAE- STRICH- TIAN	EOCENE- OLIGO- CENE?	MIOCENE
	Marrat Forma- tion	Middle Dhurma Forma- tion	Upper Dhurma Forma- tion		Yamana Forma- tion	Aruma Forma- tion		
<i>Polycyphus arabicus</i> Kier, new species		X						
<i>P. parvituberculatus</i> Kier, new species			X					
<i>Proraster granti</i> Kier, new species						X		
<i>Pseudocidaris depressa</i> Kier, new species		X						
<i>P. rarituberculata</i> Kier, new species			X					
<i>P. romani</i> Kier, new species			X					
<i>Pseudosalenia magniprocta</i> Kier, new species		X						
<i>Pygurostoma</i> cf. <i>P. morgani</i> Cotteau and Gauthier						X		
<i>Pygurus</i> (<i>Pygurus</i>) <i>arabicus</i> Kier, new species			X					
<i>P. (P.) yamamaensis</i> Kier, new species					X			
<i>Rhynchopygus arumaensis</i> Kier, new species						X		
<i>Schizechinus pentagonus</i> Kier, new species								X
<i>Zuffardia</i> cf. <i>Z. cerullii</i> Checchia-Rispoli						X

FIGURE 3.—Range of the middle Dhruma echinoids: 1. *Polycyphus arabicus* Kier, new species; 2. *Pseudosalenia magniprocta* Kier, new species; 3. *Leioechinus namus* Kier, new species; 4. *Acrosalenia dhrumaensis* Kier, new species; 5. *Acrosalenia arabica* Kier, new species; 6. *Pseudocidaris depressa* Kier, new species; 7. *Heterosalenia dhrumaensis* Kier, new species; 8. *Farquharsonia crenulata* Kier, new species; 9. *Plesiechinus altus* Kier, new species (this species is known from the "middle" but has not been collected at a measured section); 10. *Bothryopneustes dhrumaensis* Kier, new species; 11. *Bothryopneustes arabica* Kier, new species.

UPPER DHRUMA FORMATION

The upper Dhruma Formation is composed of a lower Atash Member of calcarenitic and aphanitic limestone approximately 25 meters thick at the reference section where we made our collections, and an upper section, the Hisyan Member, composed of 64

meters of calcareous shale. All the echinoids came from the lower section. In fact, twelve of the thirteen species from the upper Dhruma were collected at one horizon 11 meters above the base of the upper Dhruma at measured section KK9 (Figure 1). Only *Pygurus* (*Pygurus*) *arabicus* Kier, new species, was not found here.

The upper Dhruma is richly fossiliferous with many species of corals, sponges, mollusks, Foraminifera, ostracods, and brachiopods. Imlay (1970) reports sixteen species of ammonites from the upper Dhruma. Powers, Ramirez, Redmond, and Elberg (1966:D47) give a comprehensive list of the species of Foraminifera, ostracods, mollusks, and corals from the Dhruma Formation.

The following species of echinoids were found in the upper Dhruma Formation:

- Acrosalenia bowersi* Kier, new species
- Pseudocidaris romani* Kier, new species
- Pseudocidaris rarituberculata* Kier, new species
- Hypodiadema nanituberculata* Kier, new species
- Heterosalenia brocki* Kier, new species
- Heterosalenia ornata* Kier, new species
- Farquharsonia somaliensis* Currie
- Leioechinus amplius* Kier, new species
- Polycyphus parvituberculatus* Kier, new species
- Holactypus phelani* Kier, new species
- Pygurus* (*Pygurus*) *arabicus* Kier, new species
- Bothryopneustes kauffmani* Kier, new species
- Bothryopneustes inflata* Kier, new species

Imlay (1970:7) assigned a middle Callovian age to the upper Dhruma Formation on the basis of the ammonites. The echinoids confirm this age assignment. *Farquharsonia somaliensis*, the only Arabian species occurring outside of Arabia, has been reported from the Callovian of British Somaliland. *Pygurus* (*Pygurus*) *arabicus* is very similar to *P. (Pygurus) smelliei* Currie also from the Callovian of British Somaliland. *Pseudocidaris romani* and *P. rarituberculata* are very similar, and one of the species may be conspecific with *P. migliorinii* Maccagno from the Callovian-Oxfordian of Italian Somaliland.

RELATIONSHIP BETWEEN MIDDLE AND UPPER DHRUMA ECHINOID FAUNAS

It is significant that the middle and upper Dhruma echinoid faunas do not contain any of the same echinoid species. None of the thirteen upper Dhruma species occurs among the eleven lower Dhruma species.

Furthermore, the upper *Dhruma* species are quite distinct from the lower *Dhruma* species of the same genus. This great difference suggests either a major environmental change and a major time interval, or both, between the time of deposition of the beds containing the two faunas. The echinoid faunal break coincides with one found by Imlay (1970:D7 and oral communication, 1971) in the ranges of the ammonites. He reports no ammonites ranging from the middle *Dhruma* to the upper *Dhruma*, and suggests that the lower Callovian may be represented by a disconformity between the middle and upper *Dhruma*, or the lower 11 meters of the upper *Dhruma*. Although a few echinoid specimens have been collected in float from the lower 11 meters, I suspect that they came from the main echinoid-bearing bed 12 meters above the base, and that the upper *Dhruma* echinoid species do not extend into these lower beds.

This disconformity, if it encompassed all the early Callovian, could not represent a time hiatus of more than 2–3 million years. The fact that the lower Miocene echinoids of Arabia are strikingly similar to Recent species, having lasted 15 million years with little change, suggests that the echinoids evolved at a faster rate during this Jurassic time in Arabia than since the lower Miocene. There is no evidence of a major change in the environment that could explain this dichotomy in the faunas, for all but two of the genera present in the middle *Dhruma* are also present in the upper, including *Acrosalenia*, *Heterosalenia*, *Pseudocidaris*, *Polycyphus*, *Farquharsonia*, *Leioechinus*, and *Bothryopneustes*. The two faunas generally are morphologically similar and probably lived in similar environments.

Upper Jurassic—Tuwaiq Mountain Limestone

The Tuwaiq Mountain Limestone was defined by Steineke, Bramkamp, and Sander (1958); more details and particulars are given in Powers, Ramirez, Redmond, and Elberg (1966). The base of this formation forms a prominent cuesta extending a distance of more than 1,200 kilometers, with a maximum outcrop of 20 kilometers, and a maximum thickness of 215 meters. The western boundary is marked by a west-facing vertical limestone cliff. In the region where the echinoids were collected it is a massively bedded aphanitic limestone except in its lower part

where it is a well-bedded, very fossiliferous, soft, chalky limestone with some soft calcarenitic limestone, calcarenite, and shale. Although only one echinoid species, *Bothryopneustes orientalis* Fourtau, has been found in the Tuwaiq Mountain Limestone, it occurs in great numbers in the lower part. The echinoid was collected at six localities but in only one of them is its exact stratigraphic position known and at this place it was found 14 meters above the base of the formation. *B. orientalis* is known elsewhere from the Callovian of Egypt and the Callovian-Oxfordian of Italian Somaliland. Arkell (1952) considered the lower beds of the Tuwaiq Mountain Limestone to be middle Callovian, as did Imlay (1970:7), both on the basis of the ammonites.

Lower Cretaceous—Yamama Formation

This formation was defined in a publication by Steineke, Bramkamp, and Sander (1958:1308) and further redefined by Powers, Ramirez, Redmond, and Elberg (1966:D70). The formation crops out in a thin, curved band extending nearly 300 kilometers, with a maximum width of 9 kilometers and a maximum thickness of 45 meters. It is largely a carbonate unit of calcarenite, calcarenitic limestone, and aphanitic limestone.

Although Redmond (1964) has described several Foraminifera from this formation, his species are restricted to Saudi Arabia and are of no assistance in determining the age of the formation. Many mollusks occur in the formation but they have not yet been described. The only evidence for age comes from the echinoids. The species *Pygurus* (*Pygurus*) *yamamaensis* occurs in great numbers in the lower part of this formation. This species is most similar to the Neocomian species *Pygurus montmolini* Agassiz from western Europe. Furthermore, its phylloides are typical of those found in other Neocomian species as described in an evolutionary trend delineated by Kier (1962, chart 3, opposite p. 6). Jean Roger (in Steineke, Bramkamp, and Sander (1958:1308) identified a species of *Trematopygus* similar to *T. grasi* d'Orbigny known from the Valanginian of France, but no specimens were well enough preserved in the collection I studied to permit a more exact identification. In summary the echinoids indicate that the Yamama Formation is Neocomian.

Upper Cretaceous—Aruma Formation

The Aruma Formation was defined by Steineke, Bramkamp, and Sander (1958:1310). It crops out over a distance of about 1,600 kilometers with a width ranging from 20 kilometers in the south to 200 kilometers in the north where it passes into Iraq. Its thickness is 140 meters at the type locality. More details are given in Powers, Ramirez, Redmond, and Elberg (1966: D79–D83). The echinoids all came from the lower part of the Aruma where it is a cream, fine-grained nodular bedded calcarenitic limestone. Eleven echinoid species are present:

Coptodiscus nomiae Cotteau and Gauthier
Globator mortenseni Checchia-Rispoli
Rhynchopygus arumaensis Kier, new species
Proraster granti Kier, new species
Goniopygus superbus Cotteau and Gauthier
Actinophyma cf. *A. spectabile* Cotteau and Gauthier
Iraniaster affinemorgani Kier, new species
Iraniaster affinidouvillei Kier, new species
Iraniaster bowersi Kier, new species
Zuffardia cf. *Z. cerullii* Checchia-Rispoli
Pygurostoma cf. *P. morgani* Cotteau and Gauthier

One of the more interesting aspects of this fauna is the presence of the pair of species of *Iraniaster*—*I. affinemorgani* and *I. affinidouvillei*. These species occur together at the same localities and same stratigraphic level and are another example of sympatric pairing in spatangoids. Chesher (1968) discusses in great detail the occurrence of sympatric pairs in both the Recent and fossil record. He notes that there is consistently a high and low form. This is also true with these Arabian species. This discovery is even more interesting in light of the fact that another sympatric pair of species of this same genus is present from the Senonian of Iran—*Iraniaster morgani* Cotteau and Gauthier and *I. douvillei* Cotteau and Gauthier. These species likewise consist of a low and high form. Unfortunately, the age relative to each of these Arabian and Iranian species is not known, but morphologically the Arabian species appear to be more advanced. The plastron of the Arabian *I. affinemorgani* is much more advanced than *I. morgani*. Its plastron is composed partially of a second plate (2a); whereas in *I. morgani* the plastron is more primitive, with only one plate. Furthermore the more deeply depressed petals of the Arabian species indicate that they are more specialized for burrowing than the Iranian. *I. affinemorgani*

appears to be descended from *I. morgani*; whereas *I. affinidouvillei* is descended from *I. douvillei*. *I. affinidouvillei* is more similar to the Iranian *I. douvillei* than to its sympatric partner *I. affinemorgani*.

This fauna has close affinities with a fauna described by Cotteau and Gauthier (1895) from the Senonian of Iran. Both *Coptodiscus nomiae* and *Goniopygus superbus* occur in Iran (*C. nomiae* is also present in the Campanian of Oman), and there are some Arabian specimens very similar to the Senonian Iranian species *Pygurostoma morgani* and *Actinophyma spectabile*. *Proraster granti* is very similar to *P. morgani* (Cotteau and Gauthier), *Iraniaster affinemorgani* is similar to *I. morgani* Cotteau and Gauthier, and *I. affinidouvillei* is similar to *Iraniaster douvillei* Cotteau and Gauthier, all three from the Senonian of Iran.

The fauna also has affinities with some northeastern African echinoids. *Globator mortenseni* was first described from the Maestrichtian of Tripolitania (Libya). One Aruma specimen is very similar and probably belongs to *Zuffardia cerullii* Checchia-Rispoli, also from the Maestrichtian of Tripolitania. Finally, *Rhynchopygus arumaensis* is quite similar to *R. hori* (Fourtau) from the Aptian of Egypt.

The fauna is distinct from faunas of similar age in Europe, India, and Pakistan and is apparently confined to the central Tethys. On the basis of the echinoids, it is certainly Senonian and probably Campanian or early Maestrichtian. Powers, Ramirez, Redmond, and Elberg (1963:83) considered the lower part of the Aruma to be Campanian on the basis of the Foraminifera and mollusks.

Tertiary

EOCENE—OLIGOCENE?

Three species of echinoids occur at two localities (S-761, S-1603) at the northwestern tip of Saudi Arabia in the Wadi Sirhan area. These species were collected from a sandy marl that has been dated tentatively as Eocene according to the geological map of Saudi Arabia (1963). Detailed stratigraphic relationships and formal nomenclature for the units in the area were never established. According to Dr. O. W. Nine (1970, personal correspondence), "S-761 was collected by Schultz and Wells from the Lower (sandy) Marl Member of the Sirhan Formation in

1939. (These are informal rock names and were never adopted.) The late Dr. R. A. Bramkamp dated the contained fauna as Miocene in 1940. He held the opinion the beds were near equivalent of the Syrian Burdigalian because they contained a probable *Schizaster parkinsoni* DeFrance." However, no specimens of a *Schizaster* are present among the specimens I have studied from this locality or from S-1603. The three species that occur are *Echinodiscus ginauensis* Clegg, *Agassizia arabica* Kier, new species, and *Eupatagus* species. *Echinodiscus ginauensis* is known from Iran where Clegg (1933:4) reported it from strata below a bed with nummularies, and reported that Pilgrim mentioned having found a limestone in the same region crowded with *Echinodiscus*, *Orthophragmina*, and *Assilina spira*. On the basis of these latter two Eocene Foraminifera, Clegg considered *E. ginauensis* to be of Khirthar (middle Eocene) age. Although the Foraminifera cannot be younger than Eocene, I am suspicious of the Eocene age for the echinoid. No *Echinodiscus* is known elsewhere from below the Miocene and no *Amphiope* (a very closely allied genus) is known from before the Oligocene. Furthermore, *E. ginauensis* has lunules, and I know of no sand dollar with lunules before the Oligocene.

Agassizia arabica resembles most *A. powersi* from the Burdigalian Dam Formation of eastern Saudi Arabia but appears to be ancestral. *Eupatagus* species is quite distinct from all other species of this genus and provides no information relative to its age. Therefore, no definite age determination can be made of these echinoids, but they are probably late Eocene or Oligocene.

Some echinoids have been collected from Eastern Aden (Beydoun 1966:H37) from the middle Eocene Habshiya Formation. Five of the species also occur in the Karkar Series of British Somaliland and it is apparent that these two regions once belonged to the same faunal province. No echinoids of the same age have been found in Saudi Arabia and therefore it is not possible to know whether this echinoid province extended northward into Saudi Arabia.

MIocene—DAM FORMATION

The Dam Formation was first published by Thralls and Hasson (1956) with type-section details given by Steineke, Bramkamp, and Sander (1958:1313) and Powers, Ramirez, Redmond, and Elberg (1966:

D95). The formation crops out near the coast of the Persian Gulf in northeastern Saudi Arabia where it is from 30 to 100 meters thick. Further inland, it passes into continental facies indistinguishable from nonmarine beds above and below. It thus represents a transgressive wedge of the Miocene sea. In its marine facies, it is a marl with minor interbeds of sandstone, chalky limestone, and coquina. Fossils are abundant locally throughout the formation, but the most prominent marker bed is the "Button bed" which is composed of large numbers of *Fibularia damensis* Kier, new species (called *Echinocyamus* species in all previous works).

Nine species of echinoids occur in the Dam Formation:

Schizechinus pentagonus Kier, new species
Fibularia damensis Kier, new species
Laganum tumidum Duncan and Sladen
Echinodiscus desori Duncan and Sladen
Brissus latidunensis Clegg
Lovenia cf. *Lovenia elongata* (Gray)
Moiria adamthi Clegg
Agassizia powersi Kier, new species
Opechinus costatus (d'Archiac and Haime)

This formation is middle Miocene according to Steineke, Bramkamp, and Sander (1958), and Powers, Ramirez, Redmond, and Elberg (1966:D97). They state that it approximately correlates with the Lower Fars Formation of Iraq, as indicated by the "presence of *Ostrea latimarginata* Vredenburg *Echinocyamus* sp., and "Archaias" sp. —." Their "*Echinocyamus*" sp. is *Fibularia damensis*, but no *Echinocyamus* or *Fibularia* have been reported from the Lower Fars. Powers, Ramirez, Redmond, and Elberg, however, list from the Dam many other echinoids that also have been reported from the Lower Fars, including *Agassizia* cf. *A. scrobiculata* Valenciennes var. *persica* Clegg (herein referred to *Agassizia powersi* Kier, new species), *Brissus latidunensis* Clegg, *Lovenia elongata* Gray, *Moiria adamthi* Clegg, and *Temnopleurus persica* Clegg. I have found all these except *Temnopleurus persica* and agree with these authors that the Dam correlates with the Lower Fars. Furthermore, *Laganum tumidum*, which occurs in the Dam, is also known from the Fars.

Although Powers et al. considered on this evidence that the Dam was middle Miocene, the Lower Fars is now considered to be Burdigalian by most recent authors, or upper lower Miocene. Of the four species that also occur in the Fars Formation, only one

(*Brissus latidunensis*) has been reported definitely as occurring in the Lower Fars. The others are reported from the Fars without any indication as to whether they are from the Lower, Middle, or Upper Fars. Three of these species, *Lovenia elongata*, *Moiria adamthi*, and *Brissus latidunensis*, however, occur together in the Dam at the same locality and stratigraphic position, so it is a fair assumption that they also occur together in the Lower Fars. Clegg (1933:5) reported that *Brissus latidunensis* came from the

Lower Fars in beds that he considered to be Burdigalian or Helvetian.

Eames, Banner, Blow, and Clarke (1962:12, 15) put the lower part of the Lower Fars in the Burdigalian and correlated it with the Gaj Series of Pakistan and India. Two of the Dam echinoids, *Opechinus costatus* and *Echinodiscus desori*, are known from the Gaj. Furthermore, *Ostrea latimarginata* Vredenburg, which is present in the Dam Formation, is considered an "index fossil" of the Lower Fars (van

FIGURE 4.—Distribution of the Arabian Miocene echinoids within and outside of Arabia. The species are represented by the following symbols: O = *Opechinus costatus* (D'Archiac and Haime); □ = *Moiria adamthi* Clegg; △ = *Laganum tumidum* Duncan and Sladen; ● = *Agassizia powersi* Kier, new species; ■ = *Brissus latidunensis* Clegg; ▲ = *Lovenia elongata*.

Bellen 1959:166) and also is known from the Gaj (Eames, Banner, Blow, and Clarke 1962:15). It is evident that the Dam and Lower Fars also correlate with the Gaj. Contemporary workers consider the Gaj to be Burdigalian on the basis of the Foraminifera and mollusca (Mohan and Chatterji 1956; and Eames, Banner, Blow, and Clarke 1962:15). Therefore, these Dam echinoids are probably Burdigalian.

PALEOGEOGRAPHY.—Geographically, the echinoids of the Dam Formation are part of an echinoid faunal province extending from the west side of the Persian Gulf in Arabia, through southern Iran, southern Pakistan, and northwestern India (Figure 4). None of the species has been reported from anywhere else.

There is no evidence that all the species reported from the Dam Formation lived together at the same time. Five of the species are found at the same locality: *Echinodiscus desori*, *Lovenia* cf. *L. elongata*, *Moiria adamthi*, *Brissus latidunensis*, and *Schizaster pentagonus*. It is not known for certain, however, that they all came from the same stratigraphic level. *Fibularia damensis* occurs with *Opechinus costatus* at one and possibly two localities, and with *Agassizia powersi* at one locality. The exact stratigraphic position within the Dam Formation is known for only one species, *Fibularia damensis*, which is reported in Powers, Ramirez, Redmond, and Elberg (1966:D146) as occurring 11.8 meters above the base of the Dam at its type section.

COMPARISON WITH LIVING SPECIES.—I am surprised by the great similarity between many of the species of echinoids in the Dam Formation and species now living. The Burdigalian is considered by the most recent estimates (Berggren 1969:1073) to be at least 14 million years old, but some of the Dam species have undergone little or no change during this long period of time. *Brissus latidunensis* Clegg is indistinguishable from the living *B. agassizii* Döderlein, and only the lack of sufficient specimens prevents decision as to whether it is really conspecific. The specimens from the Dam referred tentatively to *Lovenia elongata* are indistinguishable from this living species. *Agassizia powersi* is very similar to the living *A. scrobiculata* Valenciennes, and *Moiria adamthi* Clegg strongly resembles *M. stygia* Lütken. *Laganum tumidum* Duncan and Sladen is so similar to the living *L. depressum* L. Agassiz that most authors have considered them

to be synonymous. Furthermore, all these above echinoids are very advanced, highly specialized spatangoids or clypeasteroids far removed from the old conservative stocks, such as the cidarids.

PALEOECOLOGY.—The echinoids from the Dam Formation occur in a quartz grain, marly sandstone containing numerous shell fragments. Three of the species are conspecific or strikingly similar to species now living in the littoral zone.

Lovenia elongata (Gray) today lives on a sandy bottom from the ebbzone down to 94 meters. Clark (1938:440) observed that at low tide "it made every effort to pace with the rapidly receding tide. The long spines of the oral surface raised the entire animal very considerably from the sand as it walked upon and by means of them, while the still longer spines of the dorsal surface stood out even more strikingly as if in defense from any attack."

Moiria adamthi Clegg is quite similar to *M. stygia* Lütken, now living in the Gulf of Suez. According to Mortensen (1951:337) this species is "an eminently littoral species living buried deep in the ground." *Brissus latidunensis* Clegg may be conspecific with *Brissus agassizii* Döderlein, now living off Japan buried in shallow water down to 10 meters.

Laganum tumidum is very like *L. depressum*, a shallow-water species commonly found just below low tide on a sandy bottom.

The living habits of the echinoids would probably be as follows: *Schizechinus pentagonus* morphologically resembles the modern *Lytechinus variegatus* (Lamarck) and probably lived as it does (Kier and Grant 1965:21), in shallow water on the sandy bottom in grass with its test covered with shells and bits of grass. *Fibularia damensis* Kier occurred in great numbers in the interstices of the sand and shell fragments in the bottom sediment. Both *Laganum tumidum* and *Echinodiscus desori* would be in the littoral zone, no doubt in great numbers, with their tests covered by sand but not truly buried. *Brissus latidunensis* Clegg, *Lovenia elongata* Gray, and *Moiria adamthi* Clegg would be deeply buried in the substrate. *Opechinus costatus* is structurally very similar to *Mespilia globulus* (Linné), which I have seen living off Eniwetok Atoll, Marshall Islands, in water 10-feet deep on a sandy bottom under small loose rocks holding detritus over their tests. Presumably *O. costatus* lived similarly.

Comparison of the Echinoid Faunas of Saudi Arabia with those of North Africa, Iran, and India

The Jurassic echinoid fauna is largely endemic to Saudi Arabia with only two out of twenty-seven species occurring elsewhere (in Egypt and Somaliland). Large echinoid faunas of the same age are known from Egypt and Somaliland, and the fact that only two species are shared with the Arabian fauna indicates a high degree of endemism. The Late Cretaceous fauna has a broader distribution, extending into Iran and with close affinities with a few North African species but none to the east in India. The Miocene fauna differs in sharing no species with North Africa but in being part of a fauna occurring along the present borders of the Persian Gulf and the Arabian Sea of Saudi Arabia, Iran, West Pakistan, and northwestern India. The Miocene distribution reflects the present distribution of the land masses, whereas the Mesozoic distribution indicates faunal provinces in the Jurassic largely confined to Saudi Arabia, and in the Cretaceous confined to Iran and Saudi Arabia with some connections to North Africa but not to India.

The dissimilarity between the Mesozoic echinoids of India and Saudi Arabia and similarity in the Tertiary may support the view of some of the advocates of continental drift that the subcontinent of India was not in its present position in pre-Tertiary time. Considerable more evidence relative to this question will be available when the extensive Arabian Mesozoic collections of corals, brachiopods, mollusks, sponges, and Foraminifera have been described.

A detailed description is given below of the affinities of the Arabian echinoids.

JURASSIC.—Most of the Jurassic Arabian echinoids are distinct from those known from elsewhere, and have their strongest affinities with Egyptian and Somaliland species. Only two of the twenty-seven species reported herein are known outside of Saudi Arabia: *Farquharsonia somaliensis* Currie from Somaliland and *Bothryopneustes orientalis* Fourtau from Egypt and Somaliland. *Polycyphus arabicus* Kier, new species, is very similar to *P. drayi* Fourtau from Egypt (and *P. textilis* L. Agassiz from Madagascar and France), and likewise *Acrosalenia arabica* Kier, new species, resembles the Egyptian species *A. humei* Fourtau. *Acrosalenia dhrumaensis* Kier, new species, is very similar to the Somaliland *A. somaliensis* Cur-

rie. *Pseudocidaris romani* Kier, new species, may be conspecific with the Somaliland *P. migliorinii*. *P. raratuberculata* Kier, new species, is also similar to this Somaliland species. *Heterosalenia dhrumaensis* Kier, new species, and *H. brocki* Kier, new species resemble *H. alloiteau* Zoeke from Lebanon, and *Pseudocidaris depressa* Kier, new species, is quite similar to *P. alhadasensis* de Loriol from Portugal. Finally *Bothryopneustes arabica* Kier, new species, strongly resembles *B. galhausen* Lambert from Morocco. The presence of five species of *Bothryopneustes* in Saudi Arabia is of particular paleogeographic significance. This genus is common in Somaliland and Egypt and has been reported in Madagascar and Morocco but never outside of this African-Arabian region.

None of the Arabian species resembles Indian species. The five species from Cutch specifically identified by Gregory (1893) resemble none of the Arabian species, and it may be significant that no specimens of *Bothryopneustes* have been found in India. However, the paucity of Jurassic Indian echinoids makes it impossible to determine the significance of this lack of affinity between Indian and Arabian echinoid faunas.

CRETACEOUS.—The Late Cretaceous (Campanian or early Maestrichtian) echinoid fauna of Saudi Arabia is, like the Jurassic, distinct from faunas of similar age in Europe, India, and Pakistan. It is, however, very similar to that of Iran, and several species are very like North African species. Two species, *Goniopygus superbus* Cotteau and Gauthier and *Coptodiscus nomiae* Cotteau and Gauthier, occur in both Saudi Arabia and Iran. Specimens occurring in Saudi Arabia are very similar to the Iranian *Actinophyma spectabile* Cotteau and Gauthier and *Pygurostoma morgani* Cotteau and Gauthier. *Pro-raster granti* Kier, new species, is very similar and may be conspecific with *P. morgani* Cotteau and Gauthier from Iran. The Arabian species of *Iranaster*, *I. affinemorgani* are quite similar to the Iranian *I. douvillei* Cotteau and Gauthier and *I. morgani* Cotteau and Gauthier, respectively. *Globator mortensen* (Checchia-Rispoli) occurs in Saudi Arabia and Tripoli (Libya) and is similar to *G. orientalis* Cotteau and Gauthier from Iran. Likewise an Arabian specimen is very similar and probably conspecific with *Zuffardia cerullii* Checchia-Rispoli from Tripoli. Finally, *Rhynchopygus arumaensis* Kier, new species,

is very similar and may be conspecific with *R. hori* (Fourtau) from Egypt.

The Late Cretaceous Arabian echinoids have no known affinities with the Indian-Pakistan Late Cretaceous echinoids. Three Late Cretaceous echinoid faunas are known from India-Pakistan: the Cenomanian (?Turonian) echinoids from the Bagh Beds described by Chiplonker (1937), Fourtau (1918), and Duncan (1887); the Danian echinoids from Baluchistan described by Noetling (1894, 1897); and the Maestrichtian-Danian echinoids described by Stoliczka (1873) from the Ariyalur Group of southern India. The echinoids considered by Duncan and Sladen (1882) to be Late Cretaceous are now attributed to the Paleocene.

The Arabian echinoids bear no resemblance to the fourteen species known from the Bagh Beds. However, these Bagh echinoids are older (Cenomanian, ?Turonian) and this lack of resemblance may only reflect their age difference and may not be of paleogeographical significance. The fifteen species from the Danian of Baluchistan are also distinct from the Arabian species and from the fifty-five species described by Cotteau and Gauthier (1895), and Gauthier (1902) from the Senonian of Iran. Finally, none of the thirty-eight species from the Ariyalur Group of southern India resembles any of the Arabian-Iranian species. Hence the Arabian-Iranian fauna appears to belong to an entirely different faunal province than the Indian. Its affinity is with North Africa and not the east. Cotteau and Gauthier (1895:107) likewise noted that the Iranian echinoids resembled the North African but little resembled the echinoids of southern India. Noetling (1897:7) considered that the similarity between the echinoids of Baluchistan with those of the Pyrenees indicated that a great faunistic province extended from southwestern Europe toward Central Asia, but that this province was separated from southern India by a land barrier.

MIOCENE.—Although the Arabian Mesozoic echinoids are distinct from the Indian, the Miocene echinoids belong to a faunal province that includes southern Iran, southern Pakistan, and northwestern India (Figure 4). Two of the species that occur in Arabia are found in the Gaj Series of Pakistan and northwestern India: *Opechinus costatus* (d'Archiac and Haime) and *Echinodiscus desori* Duncan and Sladen.

Fossil Echinoid Localities in Saudi Arabia

(Prepared by H. A. McClure)

Echinoid localities in Saudi Arabia studied in this paper are, with exception of several from the northwest portion in the Wadi As Sirhan area, distributed in the outcrop belt of Mesozoic and Tertiary rocks in the approximate central eastern portion. Those that also contain ammonites are listed in Steineke and Bramkamp (1952:252–256, and fig. 3) and Im-lay (1970, table 3). Other Jurassic echinoid localities are in the same general area. Cretaceous echinoid localities are mostly from the central area of the Al Aruma plateau on outcrops of the Aruma Formation, and from the vicinity of Al Yamama near the capital city of Riyadh. Most of the Tertiary sites are near the Persian Gulf littoral and further inland, where rocks of this age crop out. The Aramco S series is from collections made by Aramco geologists between the approximate years of 1933–1953 in routine geological mapping. The Aramco L series was collected in 1961. In the KK series, the first Arabic number is the sample section designation; in the case of actual samples, the Arabic number after the hyphen indicates meters above base of the section. In the majority of cases, geographic coordinates are given, so that precise location can be determined by recourse to proper maps of the Miscellaneous Investigations series of the area compiled by the United States Geological Survey and Aramco. In several cases, where precise coordinates are not available, other data serve to place the locality approximately. All the individual localities studied in this paper, with as much pertinent information as available, are listed below.

Collector's field number	Stratigraphic assignment, description of locality, and collector
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LOWER JURASSIC—MARRAT FORMATION

KK6:¹ Base of section 21.5 meters above base of formation. Lat 24°14'N, long 46°06'E. Northern Tuwayq quadrangle.

Aramco S-989: 14 to 16 meters above base of formation. Lithology compact, fine-grained limestone,

¹ All KK locality collections were made by P. M. Kier, E. G. Kauffman, R. W. Powers, H. A. McClure, and C. D. Redmond in 1962.

in part marly and detrital, with abundant small oysters. In measured section 3.4 km. S 67° W of Al Bakhra. Lat 24°09'18"N, long 46°09'24"E. Northern Tuwayq quadrangle. Collectors: F. R. Waldron, R. A. Bramkamp, 1944.

Aramco S-1034: About 6 to 10 meters above base of formation. Lithology tan and golden, fine-grained limestone with limonite nodules. At base of isolated jebel, 24.8 km. S 1° W of Al Bakhra. Lat 23°56'36"N, long 46°11'00"E. Southern Tuwayq quadrangle. Collectors: E. L. Berg, R. L. Myers, W. T. Short, R. A. Bramkamp, 1945.

MIDDLE-UPPER JURASSIC—DHRUMA FORMATION

Aramco S-1045: 14.5 to 16.5 meters above Dhibi limestone. Golden brown, soft, oolitic limestone and fine grained, hard, marly limestone. 8.4 km. N 73.5° E of Al Bakhra. Lat 24°11.4'N, long 46°16'E. Northern Tuwayq quadrangle. Collectors: E. L. Berg, R. L. Myers, W. T. Short, R. A. Bramkamp, 1945.

Aramco S-1046: 24.8 meters above Dhibi limestone. Golden-tan oolite with thin beds of tan, soft, fine-grained limestone and tan shale. Location: same as S-1045. Collectors: E. L. Berg, R. L. Myers, W. T. Short, R. A. Bramkamp, 1945.

Aramco S-1956: Dhibi limestone, at top of escarpment. 4.5 km. N 28° E of Al Bakhra astro station. Northern Tuwayq quadrangle. Collectors: C. W. Brown, M. Steineke, E. L. Berg, R. L. Myers, W. T. Short, 1945.

Aramco S-1064: 31.6 to 34.4 meters above Dhibi limestone. Golden-tan oolite. On south side of re-entrant in scarp, 38.8 km. N 40° W of Ayn al Bakhra. Lat 23°31'00"N, long 46°16'24"E. Southern Tuwayq quadrangle. Collectors: E. L. Berg, R. L. Myers, W. T. Short, R. A. Bramkamp, 1945.

Aramco S-1148: 126 to 148 meters below top of formation. .75 km. S 70°W of Khashm al Haysiyah. Lat 24°50'27"N, long 46°01'46"E. Northern Tuwayq quadrangle. Collectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1154: Middle Dhruma. 0 to 35 meters below "B" bench. In measured section 13.5 km. N45°W of town of Dhruma. Lat 24°42'14"N, long 46°03'00"E. Northern Tuwayq quadrangle. Collectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1157: Middle Dhruma. 24.8 to 34.9 meters below "B" bench. Same locality as S-1154. Col-

lectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1160: Middle Dhruma, lower part, about 50 to 60 meters above Dhibi limestone. 3.5 km. N36°W of town of Dhruma. Lat 46°38'12"N, long 46°07'30"E. Northern Tuwayq quadrangle. Collectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1164: 13 to 32 meters below top of Dhibi limestone. 10.5 km. N53°W of N corner of town of Dhruma. Lat 24°40'06"N, long 46°03'00"E. Northern Tuwayq quadrangle. Collectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1167: 13 to 33 meters below top of Dhibi limestone. 9 km. N58¼°W of N corner of town of Dhruma. Lat 24°39'18"N, long 46°03'18"E. Northern Tuwayq quadrangle. Collectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1176: Upper Dhruma, probably Atash Member. Measured section .75 km. S70°W of Khashm al Hasiyah. Lat 24°50'27"N, long 46°01'46"E. Northern Tuwayq quadrangle. Collectors: D. A. Holm and M. P. Yackel, 1947.

Aramco S-1503: Middle Dhruma. 39.4 to 40.4 meters below *Micromphalites* clay. Golden-tan oolite and shale. 3.8 km. N89°W of town of Juraifa. Lat 25°31'48"N, long 45°13'18"E. Northern Tuwayq quadrangle. Collectors: N. J. Sander, D. B. Eicher, W. M. Furnish, O. B. Fenner, R. A. Bramkamp, 1950.

Aramco L-921:² Middle Dhruma. 2.2 meters below top of chalky limestone bench. *Dhrumaites* or *Micromphalites* zone. Lat 24°52'5"N, long 45°54'4.5"E. Northern Tuwayq quadrangle.

Aramco L-922: Middle Dhruma. 11.7 meters higher than L-921, and at same location.

Aramco L-926: Atash Member of upper Dhruma. Equivalent to level of KK9-112. Lat 24°54'N, long 45°58'34"E. Northern Tuwayq quadrangle.

KK7: Lower Dhruma. Top of section, 8.5 meters above Dhibi limestone, at Khashm Dhibi. Lat 24°12'N, long 46°11'E. Northern Tuwayq quadrangle.

KK8: Approximately lower 61 meters of middle Dhruma. Base of section 2.5 meters above Dhibi limestone, at Khashm Dhibi. Lat 24°11'N, long 46°17'E. Northern Tuwayq quadrangle.

KK9: Upper 101 meters of middle Dhruma, and all of upper Dhruma. Top of section 30 meters above

² All Aramco L locality collections were made by N. M. Layne, Jr., and H. A. McClure in 1961.

Dhurma in Tuwaiq Mountain Limestone. Lat $24^{\circ}11'N$, long $46^{\circ}19'E$. Northern Tuwayq quadrangle.

UPPER JURASSIC—TUWAIQ MOUNTAIN LIMESTONE

Aramco L-916A: Lowermost Tuwaiq Mountain Limestone. 14 meters above base of cliff. Approximately 15 km. N slightly E of town of Az Zilfi. Lat $26^{\circ}21'32''N$, long $44^{\circ}47'59.5''E$. Wadi Ar Rimah quadrangle.

Aramco L-918: Blocky, calcareous bed at base of 40 meter section near town of Az Zilfi. Lat $25^{\circ}41'14.5''N$, long $45^{\circ}11'59''E$. Northern Tuwayq quadrangle.

Aramco S-293: From Tuwayq scarp near town of Az Zilfi. S35°W of Camp Rumaythan. Approximate location: Lat $26^{\circ}18'N$, long $44^{\circ}48'$; Wadi Ar Rimah quadrangle. Collectors: M. Steineke and J. W. Hoover, 1936.

Aramco S-1800: From Tuwayq scarp near town of Az Zilfi. Finely oolitic, argillaceous, detrital limestone. Lat $26^{\circ}02'33''N$, long $44^{\circ}57'11''E$. Wadi Ar Rimah quadrangle. Collectors: S. J. Roach and W. M. Furnish, 1952.

Aramco S-1804: 24.4 to 34 meters above base of measured section. Chalky, granular and oolitic limestone. Approximately 5 km. NW of town of Az Zilfi. Lat $26^{\circ}21'06''N$, long $44^{\circ}47'13''E$. Wadi Ar Rimah quadrangle. Collectors: S. J. Roach and W. M. Furnish, 1952.

Aramco S-1805: 34 to 39 meters above base of measured section. Oolitic and detrital limestone. Location same as S-1804. Collectors: S. J. Roach and W. M. Furnish, 1952.

LOWER CRETACEOUS—YAMAMA FORMATION

KK1-41: 24.5 meters above base of formation. About 17 km. south of town of As Sulaymaniyah. Lat $24^{\circ}00'37''N$, long $47^{\circ}15'40''E$. Northern Tuwayq quadrangle.

Aramco L-901: 9.18 meters down from top of Buwaib Formation. (Questionably assigned to Buwaib Formation, but is more likely Yamama—H. A. McClure 1971.) Vicinity of Khashm ath Thamamah. Lat $25^{\circ}18'18.75''N$, long $46^{\circ}37'05''E$. Northern Tuwayq quadrangle.

Aramco L-902: At same stratigraphic level as L-901. (Questionably assigned to Buwaib Formation, but

is more likely Yamama—H. A. McClure 1971.) Yellow (limonitic) calcareous sandstone. West side of Irq Banban. Lat $25^{\circ}04'16.75''N$, long $46^{\circ}37'12.75''E$. Northern Tuwayq quadrangle.

Aramco L-905: Whitish marl, and brown, sandy limestone. About 5.75 km. S of town of As Sulaymaniyah. Lat $24^{\circ}05'48.5''N$, long $47^{\circ}18'36''E$. Northern Tuwayq quadrangle.

Aramco L-908: Lowermost part of formation. On immediate back slope of Sulaiy scarp. 8 km. SE of Al Dilam. Yellow marl. Lat $23^{\circ}58'N$, long $47^{\circ}13'E$. Southern Tuwayq quadrangle.

Aramco L-910: On level of air-drilled hole T-32. Approximate top of formation, associated with oyster bed. Approximate location: Lat $23^{\circ}55'N$, long $47^{\circ}20'E$. Northern Tuwayq quadrangle.

Aramco S-1262: 50 to 54 meters above base of formation. Molluscan and finely detrital limestone, and cream, compact, fine-grained limestone. Lat $24^{\circ}9'N$, long $47^{\circ}19.4'E$. Northern Tuwayq quadrangle. Collectors: S. B. Henry and R. A. Bramkamp, 1949.

UPPER CRETACEOUS—ARUMA FORMATION

Aramco S-71: From 3 meter member, base of which is 96.2 meters above base of measured section. Just to W of Wadi al Atj, at Khashm al Hiqaqah. Lat $25^{\circ}45'N$, long $46^{\circ}15'E$. Northern Tuwayq quadrangle. Collectors: T. W. Koch and C. W. Brown, 1934.

Aramco S-285: About 34 meters above base of formation. White marly member in hard, slabby limestone. 11.5 km. N14°E of Aqibba. Approximate location: Lat $27^{\circ}30'N$, long $44^{\circ}20'E$. Wadi Ar Rimah quadrangle. Collectors: M. Steineke and J. W. Hoover, 1936.

Aramco S-286: Probably lower Aruma. Just above sandstone of Wasia. 10.5 km. N48°W of Aqibba. Approximate location: Lat $27^{\circ}28'N$, long $44^{\circ}12'E$. Wadi Ar Rimah quadrangle. Collectors: M. Steineke and J. W. Hoover, 1936.

Aramco S-289: Lower part of formation. Tan, chalky weathering, fine-grained limestone. Approximate location: Lat $26^{\circ}16'N$, long $45^{\circ}17.5'E$. Northern Tuwayq quadrangle. Collectors: M. Steineke and J. W. Hoover, 1936.

Aramco S-290: Near base of formation. White, chalky limestone. Approximate location: Lat $26^{\circ}16.3'N$, long $45^{\circ}18.7'E$. Northern Tuwayq quad-

range. Collectors: M. Steineke and J. W. Hoover, 1936.

Aramco S-748: Lower part of formation. About 8 km. ENE of Khashm at Tawqi, on Darb at Tawqi. Approximate location: Lat 25°28'N, long 46°33'E.

Northern Tuwayq quadrangle. Collectors: T. C. Barger, J. W. Thomas and U. S. Armstrong, 1939.

Aramco S-1234: 10 to 72 meters above base of formation. Lat 25°36'40"N, long 45°52'35"E. Northern Tuwayq quadrangle. Collectors: A. F. Pocock and R. P. Kopp, 1948.

Aramco S-1419: Wadi Atj area. Northern Tuwayq quadrangle. Collectors: S. B. Henry, N. J. Sander, R. A. Bramkamp, 1949.

KK11: Lowermost Aruma. Cream, nodular bedded limestone. Between 79 and 85 kilometer markers in cut on Khurais-Riyadh road. Approximate location: Lat 25°00'N, long 47°17'E. Northern Tuwayq quadrangle.

KK12: Lower Aruma in vicinity of Khashum Buwaybiyat. Approximate location: Lat 46°49.2'N, long 25°17.4'E. Northern Tuwayq quadrangle.

TERTIARY LOCALITIES

Eocene—Oligocene

Aramco S-761: White, finely sandy marl and marly sandstone. Bottom of Wadi As Sirhan, near west side, NW of Qurayyat al Milh. Very approximate location: Lat 31°22'N, long 37°18'E. Wadi As Sirhan quadrangle. Collectors: J. R. Schultz and J. C. Wells, 1940.

Aramco S-1603: "Rashrashiyah" chalk. South side of Faida Rashrashiyah. 14.5 km. N85°W of the town of Kaf. Lat 31°25'N, long 37°20'E. Wadi As Sirhan quadrangle. Collectors: D. A. Holm and A. E. Clements, 1950.

Miocene—Dam Formation

Aramco S-126: 6 to 10 meters below red sandstone. Marl and green clay. On Jibal al Uqayr scarp, 21 km. S9°W of town of Al Uqayr. Lat 25°29'N, long 50°08'E. Western Persian Gulf quadrangle. Collectors: T. W. Koch and M. Steineke, 1935.

Aramco S-137: White marls of "button" (*Fibularia*) beds. S64°W, 23.7 km. from Jabal Qurayn. Lat

26°30'N, long 49°27'E. Western Persian Gulf quadrangle. Collectors: T. W. Koch and M. Steineke, 1935.

Aramco S-178: Weathered coquina capping hill. "Button" (*Fibularia*) beds with molluscs, crab claws, and orbitoid Foraminifera. About 1 km. E of Jabal Insib. Lat 26°13'50"N, long 49°31'40"E. Western Persian Gulf quadrangle. Collectors: M. Steineke, T. F. Harriss, F. A. Davies, J. W. Hoover, 1935.

Aramco S-357: 16 meters above *Placenta* horizon. Cream, sandy marl. Qariya al Ilya area. Probable approximate location: Lat 27°00'N, long 48°30'E. Western Persian Gulf quadrangle. Collectors: T. F. Harriss and W. H. Hoag, Jr., 1937.

Aramco S-360: Marl. Near As Sarar. Lat 26°57'N, long 48°19'E. Western Persian Gulf quadrangle. Collectors: T. F. Harriss and W. H. Hoag, Jr., 1937.

Aramco S-361: 4 meter high, conspicuous white hill in center of basin. Marl. Lat 27°22'N, long 48°25'E. Western Persian Gulf quadrangle. Collectors: T. F. Harriss and W. H. Hoag, Jr., 1937.

Aramco S-532: South side of sabkha. Al Uqayr area. Approximate location: Lat 25°30'N, long 50°12'E. Western Persian Gulf quadrangle. Collectors: M. Steineke and R. A. Bramkamp, 1936.

Aramco S-553: Upper half of "button" (*Fibularia*) bed. 1.5 to 3 meters above base of upper part of formation. Selwa area. Probable approximate location: Lat 24°45'N, long 50°42'E. Western Persian Gulf quadrangle. Collectors: T. F. Harriss and W. H. Hoag, Jr., 1937.

Aramco S-568: About 25 meters above base of upper dam. Buff and pinkish marl. Selwa area. 1.7 km. S28°W of Khashm an Nukhsh. Approximate location: Lat 24°52'N, long 50°52'E. Western Persian Gulf quadrangle. Collectors: T. F. Harriss and W. H. Hoag, Jr., 1937.

Aramco S-1392: Marl, and saccharoidal limestone. Near Al Mashakhil, NE end of jabal. Approximate location: Lat 24°31'N, long 50°53'E. Western Persian Gulf quadrangle. Collector: R. D. Gierhart (?), 1937.

Aramco S-1914: Upper part of formation. Cream, finely sandy limestone. Near Jawan quarry just off Ras Tanura road. Lat 26°42'02"N, long 49°58'04"E. Western Persian Gulf quadrangle. Collectors: H. A. McClure and R. W. Morris, 1965.

SYSTEMATICS

Detailed locality data by H. A. McClure is available in the preceding section.

The following abbreviations are used: L (length), D (diameter) S.D. (standard deviation), C.V. (coefficient of variability—the S.D. as percentage of the mean), N (number of specimens measured).

All the measurements, their means, variances, standard deviations, standard errors, variability coefficients, and counts are available by application to the curator of fossil echinoderms, National Museum of Natural History, Washington, D.C. 20560. The formula for the student t-test is available in most statistic textbooks, but in particular in Simpson, Roe, and Lewontin (1960:176).

JURASSIC SPECIES

Superorder DIADEMATACEA Duncan

Order DIADEMATOIDA Duncan

Family DIADEMATIDAE Gray

Genus *Farquharsonia* Currie

The affinities and even necessity for the erection of this genus have been argued. Currie had only two poorly preserved specimens at the time she described the genus and did not know the character of the ambulacral plates except adapically. She was convinced that her species had to be placed in a new genus but realized that she could not know its affinities until more was known about the arrangement of the ambital and adoral ambulacral plates. Mortensen (1940:333–334) questioned the need for this genus. He wrongly assumed that Currie was incorrect in her belief that the primary interambulacral tubercles were crenulate in some places on the test and noncrenulate in others. Mortensen places the genus incertae sedis in the suborder Diademina. Fell (1966:365) in the "Treatise" puts the genus in the order Pedinoida but excludes it from the family Pedinidae because "it now seems probable that the tubercles are crenulate."

Unfortunately, no part of the lantern in the type species or in *Farquharsonia crenulata* has been seen, and it is therefore not certain that the genus belongs in the superorder Diadematacea or Echinacea. The

sum of its morphological characters suggests, however, that it belongs in the Diadematacea. *Farquharsonia* belongs to the order Diadematoidea rather than the Pedinoida, as indicated by its conspicuous gill slits and generally insert ocular plates V and I. In the Pedinoida the gill slits are shallow, and the apical system dicyclic. Although the tubercles are noncrenulate in Pedinoida, the fact that some tubercles are crenulate and some noncrenulate in *F. somaliensis* suggests that this feature may not be as important as formerly thought.

Farquharsonia is quite distinct from the other diadematooid genera, resembling most *Eodiadema* in having greatly reduced tuberculation adapically, and generally having ocular plates V and I insert. *Farquharsonia* differs in having its ambulacra consisting of pairs of plates with a tubercle covering each pair separated by a single plate with a smaller tubercle, whereas *Eodiadema* has simple plates throughout most of its ambulacra except near the peristome.

Farquharsonia somaliensis Currie

FIGURES 5, 6; PLATE 2: FIGURES 3–6; PLATES 3, 4; PLATE 5: FIGURE 1

Farquharsonia somaliensis Currie, 1927:416–420, fig. 3; Mortensen 1940:333–334, fig. 167; Currie 1935:45

This species, the type species, has never been adequately described or illustrated. Currie had only two specimens available to her when she erected the genus and species from material from the Callovian of British Somaliland. These specimens were partially covered with matrix. I have borrowed these specimens from the British Museum (Natural History) and three specimens from the Sedgwick Museum which Currie identified in 1935. Two of these specimens are illustrated herein (Plate 4: figures 1–3, 6, 7; Plate 5: figure 1). The description below is based entirely on the Arabian material.

MATERIAL.—Seventeen specimens.

SHAPE.—Average horizontal diameter 18.9 (S.D. 5.2, C.V. 27.4, N=12), smallest specimen 11.8 mm, largest 27.7 mm; marginal outline circular; adapical surface inflated with gently sloping sides; adoral surface not depressed around peristome; height of test 59.2 percent of diameter (S.D. 3.8, C.V. 6.4, N=12) (Figure 5A); plates of test thin.

FIGURE 5.—*Farquharsonia somaliensis* Currie: scattergrams of the height relative to the diameter (A), diameter of peristome relative to the diameter of the test (B), number of plates in an interambulacrum (C), and number of porepairs in a half-ambulacrum (D) in specimens from Arabia and British Somaliland.

APICAL SYSTEM.—Small, width 25 percent of diameter of test of specimen 13.7 mm in diameter, 23 percent of specimen 18.7 mm in diameter, 19 percent of largest specimen 27.2 mm in diameter; periproct large, elongated in axis passing through genital 2 and ocular V (Plate 2: figure 3); genital plates pointed into interambulacra; genitals 2,3 larger than others; plate arrangement visible in seven specimens, ocular plates V and I insert in five specimens, V, II, and I insert in one (Figure 6A).

AMBULACRA.—Straight, wide, at ambitus 17.8 percent as wide as D (S.D. 0.9, C.V. 4.9, N=11), great-

est width above ambitus; interporiferous zones wide, 70–77 percent as wide as ambulacra; ambulacra from near apical system to near peristome consisting of pairs of primary plates with tubercle covering each pair, separated by single primary plate with smaller tubercle (Figure 6B); 38 porepairs in single poriferous zone in smallest specimen 11.8 mm in diameter, 48 in specimen 18.7 mm, and 57 in specimen 27.1 mm (Figure 5D); shape of pores visible on Plate 2: figure 6.

INTERAMBULACRA.—Each interambulacrum composed of 22 plates in specimen 11.8 mm in diameter, 28 in specimen 18.7 mm, 32 in largest 27.2 mm (Figure 5C).

PERISTOME.—Diameter averaging 35.9 percent of diameter of test (S.D. 4.0, C.P. 11.2, N=10) in smallest specimen 39 percent, in largest 30 percent (Figure 5B); gill slits deep, each bilobed (see Plate 3: figure 7) with elevated flange facing interambulacra.

TUBERCULATION.—Interambulacral plates bear one primary tubercle; adapically tubercles small on first six to eight plates in each half-interambulacrum (Plate 2: figure 3), scrobiculate rings of these tubercles slightly developed, not confluent, scrobicules flush to slightly depressed below general level of test; tubercles slightly above ambitus to below ambitus much larger (Plate 3: figure 1), with well-developed confluent scrobicular rings, slightly depressed scrobicules, distinct basal terraces; all primary tubercles perforate, but crenulation variable, present on most primary tubercles above and below ambitus but absent on larger tubercles at ambitus on most specimens except on one of smaller specimens (13.7 mm in diameter) in which all interambulacral primary tubercles crenulate (Plate 4: figure 5); secondary tubercles slightly developed particularly adapically (Plate 2: figure 3) where only miliaries present; slightly above ambitus, miliaries abruptly increase in size and secondary tubercles first appear extending in an irregular line with one series between primary tubercle and ambulacra and other between primary tubercle and medial suture in interambulacrum.

In ambulacra, single small, perforate, crenulate tubercle on pair of plates separated by single plate with smaller secondary tubercle (Plate 3: figure 6); as in interambulacra, miliary spines very small above ambitus.

ARABIAN LOCALITIES.—Late Jurassic, Callovian, upper Dhruma Formation, most of the specimens (12)

FIGURE 6.—*Farquharsonia somaliensis* Currie: A, apical system of hypotype USNM 170371 from the upper Dhruma Formation at locality KK9-108, $\times 7$; B, ambulacrum at midzone showing plate arrangement consisting of pairs of primary plates with tubercle covering each pair separated by single primary plate in hypotype USNM 170374 from the upper Dhruma Formation at locality KK9-112, $\times 8$.

come from KK9-112 (11 meters above the base of the upper Dhruma; two specimens from KK9-112-114 (11-13 meters above the base, one specimen from KK9-111 (14 meters above the base), one specimen at KK9-108 (7 meters above the base), and two specimens at KK9-95-96 which is in the middle Dhruma (Bathonian) one to two meters below the upper Dhruma. I suspect that these two specimens, which were float, rolled down from the higher intervals.

REMARKS.—Using an airbrasive machine, I have been able to expose many features on Currie's holotype and paratype and three other specimens she (1935:45) referred later to this species. The Somaliland specimens are indistinguishable from the Arabian. As can be seen on the scattergrams on Figure 5 the Somaliland specimens have similar diameter to height ratios, similar sized peristomes, and similar number of interambulacral and ambulacral plates in each column. The Somaliland specimens also have noncrenulate interambulacral tubercles at the ambitus but

crenulate ones below, and crenulate ambulacral tubercles. Although the Somaliland specimens are larger than the Arabian, this difference is probably of no significance, and the Arabian specimens can be referred with little doubt to *F. somaliensis*. Because no photographs have ever been published of the Somaliland specimens, several are included here (Plate 4: figures 1-3; Plate 5: figure 1).

Farquharsonia crenulata Kier, new species

FIGURE 7; PLATE 1: FIGURES 1-6; PLATE 2: FIGURES 1, 2

DIAGNOSIS.—Species characterized by all its primary interambulacral tubercles being crenulate, and large peristome.

MATERIAL.—One extremely well-preserved specimen.

SHAPE.—Test large, 27.2 mm in horizontal diameter, moderately high, 15.0 mm high or height 55 percent of diameter, with gently curving sides, marginal outline circular, adorally slightly depressed

FIGURE 7.—*Farquharsonia crenulata* Kier, new species: A, apical system of holotype USNM 170370, from the middle Dhruma Formation, $\times 10$. A photograph of this area is on Plate 1: figure 6; B, ambulacrum III of holotype, $\times 10$. A photograph of this ambulacrum is on Plate 1: figure 5; C, half-ambulacrum III at ambitus of holotype showing pair plate arrangement consisting of pairs of primary plates with tubercle covering each pair separated by single primary plate, $\times 10$. A photograph of this area is on Plate 1: figure 4.

around peristome. Test very thin as indicated by buckling of some plates (Plate 1: figure 1).

APICAL SYSTEM.—Small, 5.7 mm wide or 29 percent of diameter of test; periproct large (Plate 1: figure 6), elongated through anteroposterior axis; genital plates pointed into interambulacra; genital 2 larger than others; ocular plates V and I insert, others exert (Figure 7A).

AMBULACRA.—Straight, wide, at ambitus 4.6 mm wide or 40 percent as wide as interambulacra, greatest width above ambitus; interporiferous zones wide, 67 percent as wide as ambulacra; ambulacra from apical system to peristome consisting of pairs of primary plates with tubercle covering each pair, separated by single primary plate (Figure 7B, C) with much smaller secondary tubercle (Plate 1: figures 4, 5) (miliary adapically). Fifty-eight porepairs in single poriferous zone; outer pore of pair more elongate transversely and more adapical than inner (Plate 1: figure 4).

INTERAMBULACRA.—Each interambulacrum composed of 32 plates; at ambitus approximately 5 ambulacral plates beside each interambulacral.

PERISTOME.—Small, diameter 9.5 mm or 35 percent diameter of test; gill slits deep (Plate 2: figure 1) with elevated flange facing interambulacra, slightly bilobed.

TUBERCULATION.—Interambulacral plates each bear one primary, perforate, crenulate tubercle; adapically tubercles small on first seven or eight plates in each half-interambulacrum (Plate 1: figures 1, 5); scrobiculi of these tubercles slightly developed, flush with test; tubercles slightly above ambitus to below ambitus much larger (Plate 2: figure 2), with well-developed confluent scrobicular rings, slightly depressed scrobiculi, distinct basal terraces, 10 to 12 crenulations on each tubercle; extrascrobicular areas covered with irregularly arranged miliaries greatly reduced in size adapically.

In ambulacra, single small, perforate, crenulate tubercle on pair of plates (Plate 1: figure 4) separated by single plate with smaller secondary tubercle; as in interambulacra, miliary spines very small above ambitus.

REMARKS.—This species is congeneric with the type species and only other species of *Farquharsonia*, *F. somaliensis*. Both species share the following features: small apical system with large periproct, and

commonly ocular plates V and I insert; straight, wide ambulacra composed of pair of primary plates covered by a single tubercle separated by single plate bearing a smaller tubercle; small peristome with deep gill slits; reduced tuberculation adapically, single, perforate primary tubercle on each interambulacral plate, generally crenulate, with confluent scrobiculi; and a test composed of thin plates. *F. somaliensis* is known from the Callovian of British Somaliland and is herein reported from the Callovian (upper Dhurma Formation) of Arabia. It occurs at the same locality as *F. crenulata* but higher in the section. The specimen of *F. crenulata* came from 69 meters lower in the middle Dhurma Formation (Bathonian). *F. crenulata* differs from *F. somaliensis* in having all its primary interambulacral tubercles crenulate, in having a larger peristome, and in having its gill slits less bilobed (compare Plate 2: figure 1 with Plate 3: figure 7). However, the species are enough alike that it must be assumed that they are closely related. The fact that many of the primary tubercles in the later species, *F. somaliensis*, are not crenulate indicates that the species might have been evolving toward noncrenulate tubercles. This is significant in the light that most echinoid workers have attached considerable importance to the presence or absence of crenulations and that this feature is considered to be of ordinal importance in some groups.

TYPE SPECIMEN.—Holotype, USNM 170370.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Bathonian, middle Dhurma Formation, 106.5 meters above Dhibi Limestone Member. Locality KK9-43.

Order PYGASTEROIDA Durham and Melville

Family PYGASTERIDAE Lambert

Genus *Plesiechinus* Pomel

Plesiechinus altus Kier, new species

FIGURE 8; PLATE 32: FIGURES 1-4

DIAGNOSIS.—This species is characterized by its high test with smoothly rounded adapical surface, and steep sides.

MATERIAL.—One specimen.

SHAPE.—Test wider than long, width 32.3 mm, length 31.7, marginal outline pentagonal with apices at ambulacra; test 17.7 mm high, height 54 percent of width; adapical surface smoothly rounded, sides steep, test deeply depressed around peristome.

APICAL SYSTEM.—Central, wider than high, 5.5 mm wide, 3.1 mm high; all four genital plates in contact with periproct (Plate 32: figure 1); genital 2 largest, genital 1 smallest; no sign of genital 5.

AMBULACRA.—Narrow, greatest width 4.2 mm, 120 porepairs in single poriferous zone of half-ambulacrum; pores slightly larger adapically; plates simple primaries except near peristome (Figure 8) where several plates enlarged; petals II, III, IV straight, petals V and I curving posteriorly from apical system.

INTERAMBULACRA.—Twenty-four plates in each half-interambulacrum.

PERIPROCT.—Supramarginal, in contact with genital plates, nearly flush with test, 12.1 mm long, 6.4 mm wide, widening adorally.

PERISTOME.—Central, circular, 6.8 mm in diameter, gill notches well developed.

TUBERCULATION.—Tubercles eroded from test.

COMPARISON WITH OTHER SPECIES.—I hesitate to erect a new species on just one specimen, but this genus has never been reported from the Middle East, and its occurrence here is of significance. This species

is easily distinguished from all the other species of this genus by its inflated test with steep sides.

TYPE.—Holotype, USNM 170419.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Bathonian, middle Dhruma Formation, locality L-921 which according to Imlay (1970:8) is in the *Micromphalites*, *Dhrumaites* zone.

Superorder ECHINACEA Claus

Order SALENIOIDA Delage and Hérouard

Family ACROSALENIIDAE Gregory

Genus *Acrosalenia* L. Agassiz

Four species of *Acrosalenia*, all new, occur in the Jurassic of Arabia. The oldest is the Toarcian *A. marratensis* from the Marrat Formation, followed by *A. arabica* from the Bathonian middle Dhruma, and *A. dhrumaensis* which overlaps with it and extends slightly above it. The youngest species is *A. bowersi* from the Callovian upper Dhruma Formation. These species are distinct from each other, and there is no evidence that they are members of the same stock. No obvious evolutionary trends are discernible between them. The youngest species is the largest, but this may or may not be significant, because too few specimens are present in two of the species to be able to predict the size of these species. No trend is present in the height of the test, which is 50 percent of the diameter of the test in the oldest species *A. marratensis*, 60 percent in *A. arabica*, 47 percent in *A. dhrumaensis*, and 52 percent in the youngest *A. bowersi*. Although the apical system is largest in the oldest species *A. marratensis*, with a length 45 percent of the diameter of the test, it is smallest in the next oldest *A. arabica* (30 percent), slightly larger in the next species *A. dhrumaensis* (35 percent), and larger again in the youngest *A. bowersi* (35–42 percent). Likewise there is no trend in the number of suranal plates. Their number is not known in *A. marratensis*, but 2–4 are present in *A. arabica*, 1–2 in *A. dhrumaensis* and 2–4 in *A. bowersi*. The number of ambulacral plates are similar in all four species, but it may be significant that the oldest species has the smallest number of interambulacral plates. As a result its plates are higher relative to their width than in the other species. Likewise it may

FIGURE 8.—*Plesiechinus altus* Kier: adoral ambulacral area of the holotype USNM 170419 from the middle Dhruma Formation at locality L-921, $\times 12$.

be significant that the differentiation of the primary tubercles is less developed in the two older species. The primary tubercles in *A. marratensis* do not increase abruptly at the ambitus, whereas there is some increase in *A. arabica* and considerable increase in *A. dhrumaensis*. Furthermore, the scrobicules are not depressed in *A. marratensis* and are circular, whereas in *A. arabica* they are slightly depressed and slightly subcircular, and in *A. dhrumaensis* they have very deep scrobicules which are much lower than wide. These trends do not continue to the youngest species, *A. bowersi*, which is rather intermediate in these characters between *A. dhrumaensis* and *A. arabica*. Finally, it also may be significant that although the older species have bigeminate ambulacral plates alternating with single primary plates, the youngest species, *A. bowersi*, has trigeminate plates. In summary, the older species have less differentiated interambulacral primary tubercles with less depressed and more circular scrobicules, higher interambulacral plates, and bigeminate ambulacral plates.

Acrosalenia marratensis Kier, new species

PLATE 27: FIGURES 3-7; PLATE 28: FIGURE 1

DIAGNOSIS.—Species characterized by large apical system, 45 percent as long as test, and nonconfluent tubercles which do not increase in size abruptly at the ambitus.

MATERIAL.—This description is based on one well-preserved specimen showing clearly the surface ornamentation and plate arrangement from locality S-1054. Two other specimens are present from locality KK6-14.

SHAPE.—Test small, subcircular, 19.1 mm wide, 18.1 mm long (as measured through axis passing through ambulacrum III, interambulacrum 5), 9.2 mm high; adapical surface moderately inflated, adoral flat, not depressed around peristome.

APICAL SYSTEM.—Genital and ocular plates not preserved but margin of system indicating large apical system, 8.3 mm long, 6.1 mm wide, extending deeply posteriorly into interambulacrum 5; other genitals indented slightly into interambulacra.

AMBULACRA.—Greatest width at ambitus, or slightly below, where 3.15 mm wide, 42 percent as wide as interambulacra; poriferous zone straight from apical system to ambitus where becoming slightly arcuate in threes (Plate 27: figure 7) from there to peri-

stome; at ambitus pore zone approximately 40 percent as wide as half-ambulacrum; inner pore of pair slightly adoral to outer; 44 porepairs in half-ambulacrum; 4-5 ambulacral plates for each interambulacral plate at ambitus; ambulacra at ambitus composed of pairs of plates with large primary tubercle on each pair, separated by single primary plate with smaller tubercle; this pattern extending to near peristome, and approximately midway from ambitus to apical system; first 10-15 plates in each half-ambulacrum simple primaries with single small tubercle on each plate (Plate 27: figure 6).

INTERAMBULACRA.—Each half-interambulacrum composed of 10 plates.

PERISTOME.—Diameter 40 percent of diameter of test; gill slits not sharply indented, shallow, 0.38 mm deep; notches with elevated flanges facing interambulacra (Plate 27: figure 4).

TUBERCULATION.—Primary tubercles perforate, crenulate; interambulacral tubercles gradually increasing in size from apical system to ambitus, decreasing in size from ambitus to peristome; tubercles shifting in position from near ambulacra on adapical plates (Plate 27: figure 6) to nearer middle of plate at ambitus (Plate 28: figure 1), and nearer medial suture near peristome; dimensions of ambital interambulacral tubercle: width of plate, 3.8 mm; width of scrobicule, 2.56; width of basal terrace, 1.52; width of boss at platform, 0.85; height from top of mamelon to base of basal terrace, 0.99; 10-11 crenulations on each boss; sides of boss straight; scrobicules not depressed below level of extrascrobicular surface; scrobicules not confluent; secondary tubercles covering area outside of scrobicules, no medial naked zone; one larger secondary tubercle present on most of ambital interambulacral plates near ambulacral in adapical region of each plate (Plate 28: figure 1). Ambulacral tubercles much smaller than interambulacral; reaching their largest size at ambitus or slightly below (Plate 27: figure 7).

COMPARISON WITH OTHER SPECIES.—Although clearly an *Acrosalenia*, this species is easily distinguished from the other Arabian species of this genus by its far larger apical system, with a length 45 percent of the diameter of the test as opposed to 30-35 percent in *A. arabica* and *A. dhrumaensis*. The ambital tubercles in *A. marratensis* are not confluent nor do they increase abruptly in size near the ambitus as in the other Arabian species.

TYPE SPECIMEN.—Holotype, USNM 170411.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Lower Jurassic, Toarcian, Marrat Formation, 10.2–35.5 meters above base. Localities S–1034, KK6–14.

Acrosalenia arabica Kier, new species

FIGURES 9, 10; PLATE 28: FIGURES 2–5; PLATE 29; PLATE 30: FIGURES 1–4

DIAGNOSIS. — Species characterized by high test (height 60 percent of diameter), gently sloping sides, genital plates 1, 2, 3, and 4 large, two to four suranal plates, large peristome (40 percent of diameter of test), and slightly depressed scrobicules.

MATERIAL.—219 specimens can be referred to this species, most of which were collected from sections KK8 and KK9 from a vertical interval 92.5 meters thick. The specimens were collected as float on these two measured sections, and therefore it is not possible to describe a population. A detailed comparison was made between specimens from two widely separate intervals: KK9 from 30 to 40 meters and KK8 from 30 to 40 meters. No significant differences were found between these two groups of specimens, described below in greater detail. The following species description, however, is based only on the 155 specimens found in section KK8 from 30 to 40 meters.

SHAPE. — Test small, average specimen approximately 15 mm in diameter, smallest 7.5, largest 21.5; marginal outline varying from circular to slightly pentagonal, ambulacra forming apices; many tests slightly wider than long, with width 0 to 5 percent greater than length; height in larger specimens averaging 60 percent of diameter, 55 percent in smaller; adoral surface flattened, not depressed around peristome; adapically interambulacra slightly depressed medially in each area in some specimens.

APICAL SYSTEM.—Genital and ocular plates preserved on most specimens, suranal on only three; apical system large, length approximately 30 percent of diameter of test in adult; prolonged into posterior interambulacrum, width of system approximately 85 percent of length; genital plates pointed into interambulacra, genital 2 (Figures 9A,B) largest, genital 5 much smaller than others, forming together with posterior oculars a ring around periproct; oculars II, III, and IV exert, but V and I insert; three suranal plates present in two specimens (Figure 9A; Plate 28: figure 5); four in third (Figure 9B; Plate 30: figure

1); number of facets for suranal plates in rest of specimens suggests that there were always more than one but not more than four; periproct longer than wide, length approximately 15 percent of diameter of test.

AMBULACRA.—Narrow, at ambitus 45 percent as wide as interambulacra; poriferous zone straight, approximately 40 percent as wide as half-ambulacrum; inner pore of pair highly adoral to outer; inner pore entering test vertically, outer obliquely tilted toward perradial suture (radial water vessel); 26 porepairs in half-ambulacrum of smallest specimen 7.5 mm in diameter, 46 in specimen 16.3 mm in diameter, 56 in specimen 21.5 mm in diameter; rate of introduction of new plates slightly decreasing in larger specimens (Figure 10c); 4.5 ambulacral plates for each interambulacral plate at ambitus in adult specimens; ambulacra (Figures 9c,d,e; Plate 29; Plate 30: figure 4) composed of pairs of plates (largest adoral) with a large primary tubercle on each pair, separated by a single primary plate with a smaller tubercle; this pattern extending from apical system to peristome; pores more crowded at peristome (Figure 9d; Plate 29: figure 2).

TUBERCULATION.—Primary tubercles perforate, crenulate; interambulacral tubercles abruptly (approximately doubling) increasing in size (Plate 30: figure 3) at ambitus or one plate above ambitus; two to three large tubercles in each row; tubercles decreasing in size from first tubercle below ambitus to peristome; tubercles shifting in position from very near ambulacra on adapical plates to nearer medial interambulacral suture adorally; dimensions of ambital interambulacral tubercle in specimen 16.5 mm in diameter width of plate, 4.23 mm; width of scrobicule, 1.85 mm; width of basal terrace, 1.35; width of boss at platform, 0.90; width of mamelon, 0.35 mm; height from top of mamelon to base of basal terrace, 0.52 mm; 12–15 crenulations on each boss; sides of boss slightly concave; basal terrace present on most ambital tubercles, absent on some; scrobicule slightly below level of extrascrobicular surface in some ambital tubercles, same level in others; scrobicules confluent in tubercle immediately above ambitus or at ambitus and in all tubercles adoral to ambitus, separate above; secondary tubercles covering area outside of scrobicules; ambulacral tubercles much smaller than interambulacral; boss of tubercle covering two ambulacral plates with single plate without primary tubercle sep-

FIGURE 9.—*Acrosalenia arabica* Kier, new species: A, Apical system of figured paratype USNM 170413 from the middle Dhurma Formation at locality KK8-34, $\times 13$. A photograph of this area is on Plate 28: figure 5; B, apical system of figured paratype USNM 170416 from the middle Dhurma Formation at locality KK8-35-38, $\times 13$. A photograph of this area is on Plate 30: figure 1; C, adapical portion of ambulacrum III of figured paratype USNM 170415 from the middle Dhurma Formation at KK8-35-38, $\times 13$. A photograph of this region is on Plate 29: figure 3; D, ambulacrum I at peristome of figured paratype USNM 170414 from the middle Dhurma Formation at locality KK8-30-35, $\times 13$. A photograph of this area is on Plate 29: figure 2; E, ambulacrum at ambitus of figured paratype USNM 170415 from the middle Dhurma Formation at locality KK8-35-38, $\times 13$. A photograph of this area is on

arating each primary tubercle; dimensions of ambital ambulacral tubercle in specimen 16.5 mm in diameter (Plate 30: figure 4): width of plate, 1.42 mm; width of scrobicule, 0.71 mm; width of boss, 0.45; approximately 12 crenulations on each boss.

EVOLUTION.—Because the specimens occur throughout a 92.5 meter vertical section, some evolution might be expected. A detailed comparison was made between 32 specimens from section KK8 (30–40 meters) and ten specimens from KK9 (30–40 meters). These two levels are separated by 51 meters of vertical section. The following characters were recorded for each specimen and plotted on scattergrams (Figure 10): horizontal diameter, height, diameter of peristome, number of ambulacral plates in each half-area; number of suranal plates, and number of large tubercles from the ambitus to the peristome. No separation of points occurred in any of the plots, and the two collections cannot be separated by visual examination. No evolution is evident and it must be assumed that either the rate of deposition of the sediments was rapid or the rate of evolution of the echinoid was slow.

COMPARISON WITH OTHER SPECIES.—This species resembles most *Acrosalenia humei* Fourtau (1924:12) from the Bathonian of Egypt but differs in having a higher test, as is evident on a scattergram in which the points for the Egyptian species generally fall below those of *A. arabica*. The sides of the test in *A. arabica* are more gently sloping, and genital plates 2 and 3 are smaller.

A. arabica differs from *A. somaliensis* from the Callovian of British Somaliland in having a higher test, with its height in larger specimens averaging 60 percent of the diameter as opposed to 53 percent in *A. somaliensis*. The peristome is larger in the Arabian species, averaging a diameter that is 40 percent of that of the test as opposed to 33 percent in *A. somaliensis*. Finally, the scrobicules in the interambulacral plates are much less deep in *A. arabica* (Plate 29: figure 4) than in *A. somaliensis* (Plate 26: figure 4), and in the Arabian species more than one suranal plate is present, whereas in *A. somaliensis* eight of the ten specimens showing the suranal plates had only one.

A. arabica occurs in the higher part of the section with *A. dhrumaensis*, from which it is easily distinguished by its smaller ambital tubercles, with rounder scrobicules which are flush rather than depressed,

and by its higher test, more numerous suranal plates, and wider ambulacra.

TYPE SPECIMENS.—Holotype, USNM 170412; figured paratypes, USNM 170413–170417.

STRATIGRAPHIC OCCURRENCE. — Middle Jurassic, Bathonian, middle Dhruma Formation, most of the specimens were collected between 20 and 112.5 meters above the top of the Dhibi limestone. Two specimens came from the Dhibi limestone, but because only two were found and none between the Dhibi limestone and twenty meters farther up the section, these two may be float.

LOCALITIES.—S-1046, S-1056, S-1157, S-1160, S-1503, KK8-23, 30-35, 33-35, 34, 35-38, 37, 38.5, 40.5, 44, KK9-30-40.

Acrosalenia dhrumaensis Kier, new species

FIGURES 11, 12; PLATE 31: FIGURES 1-8

DIAGNOSIS.—Species characterized by low test, height 47 percent of horizontal diameter, one or two suranal plates, narrow ambulacra, large ambital tubercles which are wider than high, and depressed scrobicules.

MATERIAL.—Eight specimens.

SHAPE.—Test small, average specimen 12 mm in diameter, smallest 9.8, largest 16.1; marginal outline circular; test low, height 47 percent of horizontal diameter (Figure 12A); adoral surface depressed around peristome; adapically interambulacra slightly depressed medially.

APICAL SYSTEM.—Genital and ocular plates preserved in three specimens, suranal on two; apical system large, length approximately 35 percent of diameter of test; prolonged into posterior interambulacrum, width approximately 85 percent of length of system; genital plates pointed into interambulacra (Figure 11A; Plate 31: figure 8), genitals 1, 2, 3, 4 of approximately same size, genital 5 smaller, together with posterior oculars forming ring around posterior edge of periproct; oculars II, III, and IV exert, but V and I insert; one suranal plate present in one specimen, two in other, number of facets for suranal plate in third specimen indicates only one suranal plate was present; periproct longer than wide, length approximately 17 percent diameter of test.

AMBULACRA.—Narrow, at ambitus 30–35 percent (Figure 12B) as wide as interambulacra; poriferous

FIGURE 10.—*Acrosalenia arabica* Kier, new species: scattergrams showing the relation of the diameter of the test to the diameter of the peristome (A), to the number of tubercles from the margin to the peristome (B), to the number of plates in a half-ambulacrum (C), and a half-interambulacrum (D). Specimens from two widely separated stratigraphic levels are included and no separation of their plots occurs, indicating no evolution of these characters.

FIGURE 10—Continued

zone straight, approximately 40 percent as wide as half-ambulacrum; inner pore of pair slightly adoral to outer (Plate 31: figure 4) inner pore entering test vertically, outer obliquely tilted toward perradial suture (radial water vessel); 35 porepairs in half-ambulacrum of smallest specimen, 9.8 mm in diam-

eter; 44 in holotype, 16.1 mm in diameter; 5 ambulacral plates for each interambulacral plate at ambitus in holotype; ambulacra (Figure 11b) composed of pairs of plates (largest adoral) with a large primary tubercle on each pair (Plate 31: figure 4), separated by single primary plates with smaller tu-

FIGURE 11.—*Acrosalenia dhrumaensis* Kier, new species: A, apical system of holotype USNM 170418 from the middle Dhruma Formation at locality KK9-51.5, $\times 15$. A photograph of this area is on Plate 31: figure 8; B, ambulacrum I at ambitus in the same specimen, $\times 15$.

bercles; this pattern extending from apical system to peristome; pores more crowded at peristome.

INTERAMBULACRA. — Each half-interambulacrum composed of 10 plates in the smallest specimen, 9.8 mm in diameter, 12 plates in the largest, 16.1 mm in diameter; height of plate at ambitus between 50 and 55 percent of its width; new plates still being introduced in largest specimen.

PERISTOME.—Diameter averaging 38 percent of diameter of test; relatively larger in smaller specimen (40 percent in specimen 10 mm in diameter); gill slits moderately deep, 0.35–0.45 mm deep in specimen 16.1 mm in diameter; notches with elevated flanges facing interambulacra (Plate 31: figure 2).

TUBERCULATION. — Primary tubercles perforate, crenulate; interambulacral tubercles abruptly increasing (approximately 60 percent) in size (Plate 31: figure 5) at ambitus or one plate above ambitus; two

to three large tubercles in each row; tubercles decreasing in size from first tubercle below ambitus to peristome; tubercles shifting in position from very near ambulacra in adapical plates to nearer medial interambulacral suture adorally; dimensions of ambital interambulacral tubercle in specimen 16.1 mm in diameter: width of plate, 3.80 mm; width of scrobicule, 2.52 mm; width of basal terrace, 2.04 mm; width of boss at platform, 0.99 mm; width of mamelon, 0.52 mm; height from top of mamelon to base of basal terrace, 0.95; 10–12 crenulations on each boss; sides of boss slightly concave, more concave on adapical side of boss; scrobicule recessed below level of extrascrobicular surface; scrobicules confluent in tubercle immediately above ambitus and in all tubercles adoral to ambitus, separate above; secondary tubercles covering area outside of scrobicules; ambulacral tubercles much smaller than inter-

FIGURE 12.—Scattergrams showing the diameter of the test relative to the height of the test (A) and relative to the width of the ambulacrum (B) at the ambitus in *Acrosalenia somaliensis* and *A. dhurmaensis* Kier, new species.

ambulacral; boss of tubercle covering two ambulacral plates with single plate with smaller tubercle separating each primary tubercle (Plate 31: figure 4).

COMPARISON WITH OTHER SPECIES.—*A. dhrumaensis* is very similar to *A. somaliensis* Currie from the Callovian of British Somaliland. It differs in having a slightly lower test (see scattergram on Figure 12A); slightly smaller peristome; and smaller primary ambital tubercles which are wider relative to their height. These tubercles in *A. dhrumaensis* are approximately 67 percent as wide as the interambulacral plate upon which they occur, whereas in *A. somaliensis* the tubercles are only 58 percent as wide. Finally, the ambulacra are narrower in *A. dhrumaensis*, only 30 percent as wide as the interambulacra as opposed to 40–45 percent in *A. somaliensis*.

A. dhrumaensis is easily distinguished from *A. arabica*, with which it occurs, by its far larger ambital tubercles which are wider than high as opposed to the circular tubercles of *A. arabica*. Furthermore, its scrobicules are deeply depressed, whereas they are more flush with the extrascrobicular surface in *A. arabica*. The test is much lower in *A. dhrumaensis*, there are fewer suranal plates, and the ambulacra are narrower, only 30–35 percent as wide as the interambulacra instead of 45 percent as in *A. arabica*.

TYPE SPECIMENS.—Holotype, USNM 170418.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Bathonian, middle Dhruma Formation, two specimens from KK9–21–22.5 and six from KK9–51.5 (82–112.5 meters above Dhibi limestone).

Acrosalenia bowersi Kier, new species

FIGURE 13; PLATE 25; PLATE 26: FIGURES 1, 2

DIAGNOSIS.—Species characterized by large, low test, trigeminate ambulacral plates, and interambulacral tubercles which do not decrease in size abruptly adapically.

MATERIAL.—Four specimens, three well preserved.

SHAPE.—Test large, three specimens 21 mm in horizontal diameter, one 17 mm; marginal outline circular to subpentagonal; length (as measured through axis passing through ambulacrum III, interambulacrum 5) approximately equal to width; height 48–58 percent of length; adapical surface moderately flattened, adoral surface depressed around peristome in one specimen, not depressed in others.

APICAL SYSTEM.—Preserved on three specimens; large, length from 35–42 percent of diameter of test; prolonged into posterior interambulacrum, width between 80–90 percent of length of system; genital plates pointed into interambulacra, genitals 2, 3 largest, genitals 3, 4 slightly smaller, genital 5, together with posterior oculars, forming ring around posterior edge of periproct; oculars II, III, IV exert on two specimens but ocular II insert on one; oculars V and I insert on all specimens; four suranal plates present in one specimen, two in second, and four or more on third (number not clear because of silicification; periproct longer than wide, length in holotype 14 percent diameter of test).

AMBULACRA.—Wide, at ambitus 45 percent as wide as interambulacra; poriferous zone straight, approximately 32 percent as wide as half-ambulacrum; in holotype, 21.4 mm in diameter, poriferous zone 0.57 mm wide; inner pore of pair slightly adoral to outer, slightly less elongated transversely; 48 porepairs in half-ambulacrum in three specimens between 21.0 and 21.4 mm in diameter; 4½ to 5 ambulacral plates for each interambulacral plate at ambitus in larger specimens; ambulacra (Figure 13) composed of trigeminate plates extending from apical system to near peristome, with primary tubercle covering three plates; pores more crowded at peristome.

INTERAMBULACRA.—Each half-interambulacrum composed of 12–13 plates in larger specimens (21–21.4 mm in diameter); height of plate at ambitus between 50 and 55 percent of its width.

PERISTOME.—Diameter between 35 and 40 percent of diameter of test; gill slits deep, 0.66 mm deep in specimen 21.4 mm in diameter; notches with elevated flanges facing interambulacra (Plate 25: figure 3).

TUBERCULATION.—Primary tubercles perforate, crenulate; interambulacral tubercles gradually not abruptly increasing in size toward ambitus; tubercles shifting in position from very near ambulacra adapically to nearer medial interambulacral suture adorally; dimensions of ambital interambulacral tubercle in specimen 21.4 mm in diameter: width of plate, 4.3 mm; width of scrobicule, 2.4 mm; height of scrobicule, 1.6 mm; height from top of mamelon to scrobicule, 1.07 mm; 10–12 crenulations on each boss; sides of boss straight to slightly concave; scrobicule (Plate 26: figure 1) recessed below level of extrascrobicular surface; scrobicules confluent in first or second tubercle above ambitus and in all tubercles

FIGURE 13.—*Acrosalenia bowersi* Kier, new species: ambulacrum II of figured paratype USNM 170410 from the upper Dhruma Formation at locality S-1148, $\times 15$.

adoral to ambitus, separate above; secondary tubercles covering area outside of scrobicules; no adapical naked medial zone; ambulacral tubercles at ambitus much smaller (40 percent less in width) than interambulacral; difference in size less marked adapically (Plate 26: figure 2); boss of tubercle covering three ambulacral plates.

COMPARISON WITH OTHER SPECIES.—*A. bowersi* differs from the other species of *Acrosalenia* from Arabia in having trigeminate ambulacral plates in which the primary tubercle covers three plates throughout the length of the ambulacra. In the other Arabian species the ambulacra are composed of pairs of plates covered by a primary tubercle separated by a single primary plate with a smaller tubercle. *A. bowersi* is further distinguished from *A. arabica* by its larger, lower test, and interambulacral tubercles which are largely adapically and do not increase as abruptly in size at the ambitus. It differs from

A. dhrumaensis in its larger adapical tubercles, smaller ambital tubercles with less depressed scrobicules, more numerous suranal plates, and wider ambulacra. Finally, it further differs from *A. marratensis* in having lower interambulacral plates, depressed scrobicules, and more sharply indented gill slits.

TYPE SPECIMENS.—Holotype, USNM 170409; figured paratype, 170410.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, Callovian, upper Dhruma Formation, locality S-1148.

Genus *Heterosalenia* Cotteau

Heterosalenia dhrumaensis Kier, new species

PLATE 9: FIGURES 2-4

DIAGNOSIS.—Species characterized by three primary tubercles in each interambulacra, lack of knobs on plates of apical system, lack of depressions in transverse sutures of interambulacral plates, and low test.

MATERIAL.—One well-preserved specimen.

SHAPE.—Horizontal diameter 15.1 mm, height 8.6 mm; marginal outline circular.

APICAL SYSTEM.—Width 43 percent of diameter of test; plates thickened, covered with granules (Plate 9: figure 2); ocular plates exert except for insert ocular I; genital plates 1, 2, 3, 4 of approximately same size, genital 5 smaller because of intrusion of periproct; single suranal plate as large as larger genital plates; periproct oblong, wider than high, situated to right of center of system, adjacent to ocular plate I.

AMBULACRA.—Sinuous, broad, at ambitus 42 percent as wide as interambulacra, greatest width below ambitus, narrowing just at peristome; interporiferous zones wide, 65–70 percent as wide as ambulacra; simple primary plates from apical system to near peristome where compounded bigeminately to polyporously trigeminately; 33 porepairs in single poriferous zone; inner pore slightly adoral to outer.

INTERAMBULACRA.—Approximately eight plates in each interambulacrum; plates not depressed at sutures.

PERISTOME.—Not preserved.

TUBERCULATION.—Three large primary tubercles in each area, a smaller fourth tubercle partially developed in some areas; primary tubercles crenulate, perforate, with well-developed ring of 13–14 scrobi-

cular tubercles, not confluent with adjacent ring; scrobicules narrow, depressed below general level of test, basal terrace absent; boss with straight or slightly concave sides; mamelon undercut, circular in outline; granules cover rest of interambulacra except near peristome where occur large secondary tubercles, three or four of larger of these perforate, crenulate, ambulacra from apical system to near peristome covered with secondary tubercles in irregular arrangement except for single row of larger secondary tubercles running along margin of interporiferous zone beside inner pore of pair; near peristome, tubercles much larger, similar in size and arrangement to those in interambulacra near peristome; perforated, crenulation not certain.

COMPARISON WITH OTHER SPECIES.—This species is distinguished from both *H. ornata* and *H. brocki* in lacking the large knobs on the plates of the apical system, in not having its transverse interambulacral plate sutures depressed, and in having a lower test. It further differs from *H. ornata* in having smaller primary tubercles and in having three instead of two in each interambulacrum.

Of the non-Arabian species, *H. dhrumaensis* resembles most *H. alloiteaui* Zoeke from the Middle Jurassic of Lebanon. Both species have a small number of interambulacral primary tubercles and lack depressions in the transverse sutures of the interambulacral plates. However, the test is lower in *H. dhrumaensis*. Unfortunately, *H. alloiteaui* is based on three poorly preserved specimens and many of its specific characters are not clear in Zoeke's (1952) figures.

TYPE SPECIMEN.—Holotype, USNM 170380.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Bathonian, middle Dhruma Formation, 78.5 meters above the top of the Dhibi limestone, locality KK9-15.

Heterosalenia brocki Kier, new species

FIGURE 14; PLATES 7, 8; PLATE 9: FIGURE 1

DIAGNOSIS.—Species characterized by high test (height 64–68) percent of diameter, slight knobs on plates of apical system, and small number (4) of interambulacral primary tubercles.

MATERIAL.—Two specimens.

SHAPE.—Specimens 15.1 and 17.1 mm in diameter, 10.3 and 11.0 mm high; marginal outline pentagonal

with apices in interambulacra, sides high, steep, test high, height 64–68 percent of diameter; adapical surface flattened except for slightly inflated apical system; adoral surface flat.

APICAL SYSTEM.—Preserved on both specimens, width 40–43 percent of diameter of test, pentagonal with apices formed by ocular plates (Plate 7: figure 5; Plate 9: figure 1); single protuberance or knob on each ocular, genital, and single suranal plate, upper surface of knob flattened, granular or warty; sutures depressed between plates with deeper pits at junction of sutures (Plate 7: figure 5); ocular plates exert (Figure 14) except for insert ocular I; periproct oblong, wider than high, situated to right of center of system, adjacent to ocular I, strongly elevated rim around periproct.

AMBULACRA.—Slightly sinuous, narrow, at ambitus 30 percent as wide as interambulacra, widening below ambitus and then slightly narrowing at peristome; interporiferous zones wide, 55–60 percent as wide as ambulacra; simple primary plates from apical system (Plate 8: figure 2) to near peristome where compounded bigeminately or trigeminately; 40–43 pore-pairs in single poriferous zone; inner pore slightly adoral to outer.

INTERAMBULACRA.—Eight or nine plates in each area; depressed in transverse sutures (Plate 8: figure 1).

PERISTOME.—Diameter 41 percent of diameter of test in one specimen, 44 percent in other; circular to

FIGURE 14.—*Heterosalenia brocki* Kier, new species: apical system of figured paratype USNM 170379 from the upper Dhruma Formation at locality KK9-111, $\times 8$. For a photograph of this area see Plate 9: figure 1.

subpentagonal in outline with moderately indented gill slits (Plate 8: figure 3).

TUBERCULATION.—Four primary, crenulate, perforate tubercles in each interambulacrum (Plate 7: figure 4), well-developed ring of scrobicular tubercles, 12–14 in each ring, not confluent; scrobicule narrow, depressed below general level of test, basal terrace slight; boss with straight or slightly concave sides; mamelon undercut, circular in outline; small granules cover rest of interambulacra except near peristome where occur large imperforate, secondary tubercles (Plate 7: figure 6; Plate 3: figure 3), presence of crenulation not clear; ambulacra from apical system to near peristome covered with small secondary tubercles in irregular arrangement except for single row of larger secondary tubercles running along margin of interporiferous zone beside inner pore of pair; near peristome, tubercles much larger, similar in size and arrangement to those in interambulacra near peristome; perforation visible only on best preserved, crenulation not certain.

COMPARISON WITH OTHER SPECIES.—This species resembles in many of its features *H. ornata* Kier, new species, from the same locality but a meter higher in the section. Both species have few interambulacral primary tubercles, nodes developed on the apical plates, similar ambulacral plate arrangement and tuberculation, and depressed transverse interambulacral sutures. Probably the species are closely related. They differ in that *H. brocki* has much less prominent knobs on its apical system, higher sides to its test, and four interambulacral primary tubercles (instead of two in *H. ornata*). It differs from *H. dhrumaensis* from lower in the Dhruma Formation by its large knobs in the apical system, higher test, four instead of three primary tubercles in each interambulacrum, and depressed transverse interambulacral sutures. Of the non-Arabian species, *H. brocki* most resembles *H. alloiteaui* Zoeke from the Middle Jurassic of Lebanon. Both species have the same number of interambulacral plates and perhaps the same number of large primary interambulacral tubercles. Unfortunately, *H. alloiteaui* is based on three poorly preserved specimens, and many of its specific characters, particularly its tuberculation, are not clear in Zoeke's (1952) figures or description. Apparently, *H. alloiteaui* lacks nodes on its apical system, and its transverse interambulacral sutures are not depressed.

TYPE SPECIMENS.—Holotype, USNM 170378; figured paratype, USNM 170379.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, Callovian, upper Dhruma Formation (10 meters above contact between middle and upper Dhruma), locality KK9–111. One specimen was collected at locality S–1167 which is considered to be stratigraphically 13–33 meters below the top of the Dhibi limestone in the lower Dhruma (Middle Bajocian). This specimen is similar in every way including its matrix to the figured paratype which occurs far higher in the section. Furthermore, one specimen of *H. ornata* occurs in this lower horizon with this specimen. This species likewise occurs far higher at KK9–112. I suspect that this specimen was either mislabeled as to its locality, or S–1167 is not as stratigraphically low in the Dhruma as it has been considered to be.

Heterosalenia ornata Kier, new species

FIGURE 15; PLATE 5: FIGURES 2–6; PLATE 6

DIAGNOSIS.—Species characterized by highly inflated apical system with a large protuberance or knob on each ocular, genital, and single suranal plate; two large primary tubercles (one in small specimens) in each interambulacrum.

MATERIAL.—Twelve well-preserved specimens, and one fragment.

SHAPE.—Average horizontal diameter 15.3 mm, smallest 13.3 mm, largest 19.7; marginal outline pentagonal with apices at interambulacra; sides almost vertical, adapical surface flat except for highly inflated apical system; adoral surface flat; height of test varying from 63 to 70 percent of diameter (Figure 15A).

APICAL SYSTEM.—Preserved on all but two specimens, large, width 55 percent of diameter of test, pentagonal with apices formed by ocular plates (Plate 5: figure 4; Plate 6: figures 1, 4); ocular, genital, and single suranal plate greatly thickened with large knob rising high above general surface of apical system; upper surface of each knob flattened, overhanging lower part of knob, granular or warty; deep pits in corners of plates; in some specimens (Plate 6: figure 1) ridges join knobs of adjacent plates; ocular plates exert except for insert ocular I; periproct

FIGURE 15.—*Heterosalenia ornata* Kier, new species: scattergrams showing the height relative to the diameter of the test (A) and the number of porepairs in a half-ambulacrum relative to the diameter of the test (B).

small, wider than high, situated to right of center of system, adjacent to ocular plate I.

AMBULACRA.—Slightly sinuous, narrow, at ambitus 34 percent as wide as interambulacra, greatest width slightly below ambitus; interporiferous zones wide, 60 percent as wide as ambulacra; primary plates simple from apical system (Plate 5: figures 3, 5) to near peristome where compounded bigeminately or trigeminately; 29 to 32 porepairs in each zone in specimens from 13.5 to 15.7 mm in diameter, 42 in specimen 19.7 (Figure 15B); inner pore of pair slightly adoral to outer.

INTERAMBULACRA.—Few plates, approximately 5 to 7 in each interambulacrum but exact number not discernible because of obscurity of sutures; in some areas single plate extends across whole width of interambulacrum; interambulacra depressed at sutures between ambital and adapical plates except in suture between two plates bearing large tubercles (Plate 5: figure 6), adoral plates not depressed at sutures.

PERISTOME.—Diameter between 34 and 42 percent (average 38) of diameter of test; subpentagonal in outline with slightly indented gill slits (Plate 5: figure 2).

TUBERCULATION.—Two large primary tubercles in each interambulacrum in large specimens, one in some smaller specimens, all specimens over 14.2 mm in diameter with two, one specimen 13.5 mm in diameter with one tubercle in two interambulacra, specimen 14.2 mm with one in each interambulacrum, smallest specimen, 12.1 mm, with two; primary tubercles perforate, crenulate (Plate 5: figures 5, 6), well-developed ring of scrobicular tubercles, 11–13 tubercles, not confluent with adjacent ring; scrobicule depressed below general level of test, basal terrace absent on most tubercles, slightly developed on few; boss with straight or slightly concave sides; mamelon undercut, circular in outline; small granules cover rest of interambulacra except for naked zones where sutures depressed, and near peristome where occur large perforate, secondary tubercles (Plate 5: figure 2) crenulation not clear; ambulacra from apical system to near peristome covered with small secondary tubercles, in smaller specimens in orderly arrangement with 1–3 in single row on each plate, in larger specimens irregularly arranged, tubercle nearest porepairs larger than others (Plate 5: figure 6); near peristome secondary tubercles much larger, similar in size and arrangement to those in interambulacra near peri-

stome (Plate 5: figure 2); perforation visible on best preserved, crenulation not certain.

LANTERN.—One pyramid preserved from specimen 19.7 mm in diameter, pyramid 6.3 mm high, 3.1 mm wide, foramen magnum deep, 3.1 mm (Plate 6: figures 5–8); auricles ambulacral, two tabs expanded at tips but not joining across ambulacra.

COMPARISON WITH OTHER SPECIES.—This species because of its periproct being pushed out to the right against ocular I, rugose apical system, single suranal plate, and sinuate ambulacra with trigeminate plates below, simple primaries at and above the ambitus is placed in *Heterosalenia*. It differs, however, from the following species of this genus, *H. martini* Cotteau, *H. corallina* (Dames), *H. ottmeri* (Dames), *H. occidentalis* Hawkins, *H. paquieri* Savin, *H. pseudocidaroides* (Currie), *H. quadrimiliaris* (Currie), and *H. suatensis* Weber, in having an inflated apical system with a large knob rising high above each plate, and by having far fewer primary interambulacral tubercles in each area. In *H. ornata* only one or two primary tubercles are present, as contrasted to at least six in each area in all these other species. Of all the non-Arabian species, *H. ornata* is most similar to *H. alloiteau* Zoeke from the Middle Jurassic of north Lebanon in that both species have few interambulacral primary tubercles, but *H. ornata* differs in having an inflated apical system with a large protuberance on each genital, ocular, and the suranal plate.

This species closely resembles *H. brocki* Kier, new species, from the same locality but a meter lower in that both species have knobs on their apical plates, few interambulacral tubercles, and depressed transverse interambulacral sutures. They differ in that *H. ornata* has more prominent knobs on its apical system, lower sides to its test, and two instead of four primary tubercles in its interambulacra. *H. ornata* is easily distinguished from *H. dhrumaensis* Kier, new species, from the middle Dhruma by the high knobs on the apical system, two instead of four primary tubercles in the interambulacra, and depressed interambulacral sutures.

TYPE SPECIMENS.—Holotype, USNM 170375; figured paratypes, USNM 170376–170377.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Callovian, upper Dhruma Formation (11 meters above contact between middle and upper Dhruma), locality KK9–112. One specimen was col-

lected at locality S-1167 which is considered to be stratigraphically 13–33 meters below the top of the Dhibi limestone in the lower Dhurma (Middle Bajocian). This specimen is similar in every way including its matrix to the rest of the specimens of this species, all of which occur far higher in the section. Furthermore, one specimen of *H. brocki* also occurs with this specimen. This species likewise occurs far higher at KK9–111. I suspect that these specimens were either mislabeled as to locality, or S-1167 is not as stratigraphically low in the Dhurma as it has been considered to be.

Genus *Pseudosalenia* Cotteau

Pseudosalenia magniprocta Kier, new species

FIGURE 16; PLATE 9: FIGURES 5–7; PLATE 10; PLATE 11: FIGURES 1–4

DIAGNOSIS.—Species characterized by large periproct, more than one suranal plate, insert oculars V and I, inflated interporiferous zones, and complete ring of tubercles around each scrobicule.

MATERIAL.—Fourteen specimens.

SHAPE.—Average specimen 16.0 mm in horizontal diameter, smallest 13.2 mm, largest 18.7 mm; marginal outline circular in some specimens, slightly pentagonal in others with ambulacra forming apices (due to inflated interporiferous zones); height (Figure 16A) averaging 51 percent of horizontal diameter, varying from 47 to 53 percent; adapical and adoral surfaces flattened, sides steep; area around peristome slightly depressed in some specimens, not depressed in others.

APICAL SYSTEM.—Genital and ocular plates preserved on two specimens; apical system prolonged into posterior interambulacrum, large, length 35 to 40 percent of diameter of test; width 33 to 36 percent; genital plates pointed into interambulacra, genital 2 largest (Plate 9: figure 7), genital 5 much smaller than others, forming together with posterior oculars a ring around posterior portion of periproct; oculars II, III, and IV exert, but V and I insert; two suranal plates preserved on one specimen but evidence that there were originally more, in second specimen three suranal plates but probably originally four.

AMBULACRA.—Narrow, at ambitus 30–35 percent as wide as interambulacra; in some specimens continuing to widen below ambitus because of increasing width of interporiferous zones; inner pore of pair

slightly adoral to outer (Plate 11: figure 1), with inner pore larger and entering test obliquely tilted toward perradial suture, outer smaller, more vertical; peripodia well developed with elevated flange present along adapical inside edge of each outer pore (Plate 11: figure 1); 35 porepairs in half-ambulacrum of smallest specimen 13.2 mm in diameter, 39 in specimen 16.7 mm in diameter, 44 in specimen 18.7 mm in diameter; 6.5 ambulacral plates for each interambulacral plate at ambitus; interporiferous zones inflated; ambulacra composed of primary plates (Plate 10: figure 4) from apical system to near peristome (within ten porepairs in each half-ambulacrum) where plates compounded into approximately three trigeminate plates (Plate 11: figure 3) with adoral-most plate of each compound plate smaller, its porepair nearer perradial suture; several plates in each series occluded.

INTERAMBULACRA.—Each half-interambulacrum composed of seven plates in the smaller specimens (13–14 mm in diameter) and nine to ten in the larger specimens (18–19 mm in diameter).

PERISTOME.—Diameter averaging 47 percent of diameter of test (Figure 16B), quite variable (varying from 43 to 53 percent in larger specimens); gill slits slight, approximately 0.4 mm deep in large specimen; notches with elevated flange facing interambulacra (Plate 11: figure 3).

TUBERCULATION.—Primary tubercles perforate, crenulate; interambulacral tubercles reaching maximum size within three or four plates from apical system (Plate 11: figure 2); two to three extremely large tubercles in each row; tubercles shifting in position from near ambulacra on adapical plates to nearer medial interambulacral suture adorally; dimensions of ambital interambulacral tubercle in specimen 16.6 mm in diameter: width of plate, 3.63 mm; width of scrobicule, 2.56 mm; width of boss at platform, 1.18 mm; 11–12 crenulations on each boss; sides of boss straight to slightly concave; basal terrace present on some tubercles, absent on others; scrobicules not confluent on most specimens, separated from each other by single row of small secondary tubercles forming a scrobicular ring; secondary tubercles covering area outside of scrobicules; ambulacral tubercles much smaller than interambulacral; from apical system to near peristome one small imperforate, noncrenulate tubercle on outside edge of interporiferous zone, two or three smaller tubercles between this tubercle and

FIGURE 16.—*Pseudosalenia magniprocta* Kier, new species: scattergrams showing the height of the test relative to the diameter (A) and the diameter of the peristome relative to the diameter (B).

medial suture (Plate 11: figure 1); near peristome a single larger perforate tubercle covering two or three plates, two or three of these tubercles in each half-ambulacrum (Plate 11: figure 3).

COMPARISON WITH OTHER SPECIES.—The following characters indicate that this species belongs to the genus *Pseudosalenia*: sinuate ambulacra with simple plates bearing imperforate tubercles from the apical system to near the peristome where they are compound and bear perforate tubercles, and slightly widened ambulacra adorally.

Maccagno (1947:9, 12) referred *Acrosalenia* (*Metacrosalenia*) *pseudocidaroides* Currie (1925:55) and *Acrosalenia* (*Metacrosalenia*) *quadrimaliaris* Currie (1927:414) from the Bathonian of Somaliland to *Pseudosalenia*. Although I have studied Currie's type specimens I have not seen Maccagno's specimens and therefore will not give an opinion on the generic assignment of Currie's species. *P. magniprocta* differs from these Somaliland species in having only 6.5 ambulacral plates to each interambulacral plate at the ambitus as opposed to 11 in *A. pseudocidaroides* and *A. quadrimaliaris*, and narrower, more inflated interporiferous zones with fewer and larger granules.

Pseudosalenia magniprocta is easily distinguished from the type species *P. aspera* (L. Agassiz) from the Late Jurassic of France and Switzerland by its less inflated adapical surface, larger periproct, insert oculars V and I, smaller genital 5, more than one suranal plate, and less adorally widened ambulacra with more granules in the interporiferous zones. It differs from *P. zumoffeni* de Loriol from the Cenomanian of Lebanon in its larger periproct, more than one suranal plate, and more developed ring of scrobicular tubercles. *P. cuevasensis* de Loriol from the Cenomanian of Honduras is based on one poorly preserved specimen, and most of its specific characters are not known. *P. magniprocta* differs in having a flatter adapical surface, and a larger periproct with more than one suranal plate. It differs from *P. delgadoi* de Loriol from the Cenomanian of Portugal in having more interambulacral plates in each column, a larger periproct with more than one suranal plate and complete scrobicular rings of tubercles.

TYPE SPECIMENS.—Holotype, USNM 170383; figured paratypes, USNM 170381–170382.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Middle Jurassic, Bathonian, middle Dhruma Formation 23.8, 101 meters above Dhibi Limestone Member.

Localities KK8 30–35, 34, 35–38; KK9 30–40; S-1046, S-1160.

Order HEMICIDAROIDA Beurlen

Family HEMICIDARIDAE Wright

Genus *Pseudocidaris* Etallon

Pseudocidaris raratuberculata Kier, new species

FIGURE 17; PLATE 11: FIGURES 5, 6; PLATE 12

DIAGNOSIS.—Species characterized by four large crenulate primary tubercles in each interambulacrum, with deep scrobicules, and smaller secondary tubercles in the scrobicular ring.

MATERIAL.—Two specimens.

SHAPE.—Horizontal diameter 15.3 mm, 18.3; height 9.5, 12.5 (62–68 percent height of diameter); marginal outline subpentagonal with apices in interambulacra.

APICAL SYSTEM.—Preserved on both specimens (Figure 17; Plate 11: figure 5); small, width 30–33 percent diameter of test, greatest width along axis passing through genital 3, ocular I; genitals 2, 3 larger than other genitals; oculars exert; periproct large, irregular in outline, large, width approximately 15 percent diameter of test.

FIGURE 17.—*Pseudocidaris raratuberculata* Kier, new species: apical system of the holotype USNM 170384 from the upper Dhruma Formation at localities KK9–111, $\times 8$. For a photograph of this area see Plate 11: figure 5.

AMBULACRA.—Sinuous, narrow, increasing in width from apical system to edge of peristome; at ambitus in specimen 15.3 mm in diameter ambulacrum 1.8 mm wide, at peristome 2.2 mm; ambulacrum at ambitus 27 percent as wide as interambulacrum; 41 porepairs in half-ambulacrum of specimen 15.3 mm in diameter, 47 in specimen 18.3; inner pore of pair slightly adoral to outer (Plate 12: figure 4); plates simple primaries from apical system to near peristome; two compound plates in each half-ambulacrum near peristome.

INTERAMBULACRA.—Four or five plates in each half-interambulacrum.

PERISTOME.—Diameter 52–54 percent diameter of test; pentagonal in outline with well-developed gill slits.

TUBERCULATION.—Interambulacra: primary tubercles extremely large except near peristome (Plate 11: figure 6), first tubercle near apical system the largest, no tubercle present in adjacent plate at apical system; four large tubercles in each interambulacrum, adoral two smaller than adapical two; mamelon perforate, circular in outline, undercut; parapet with approximately 15 crenulations; sides of boss concave; no basal terrace, scrobicule merging imperceptible into boss; scrobicule deeply depressed below general level of test, not confluent; regularly spaced ring of secondary tubercles around each tubercle; rest of plate covered with smaller secondary tubercles; tubercles near peristome smaller, reducing in size toward peristome.

AMBULACRA.—Tubercles from apical system to near peristome smaller, lacking mamelons, scrobicules, no larger than secondary tubercles in interambulacra (Plate 12: figure 5); first adapical ten (approximately) plates in each half-ambulacrum (Plate 12: figure 5) with single tubercle; adoral plate until near peristome with second smaller or same size tubercle on every other plate (Plate 12: figure 4); near peristome each ambulacrum with larger primary tubercles having well-developed perforate mamelons, scrobicules (Plate 12: figure 8); presence or absence of crenulations not clear because of poor preservation in this region in both specimens.

COMPARISON WITH OTHER SPECIES.—This species is distinguished from *Pseudocidaris romani* which occurs with it by its slightly smaller and more numerous large primary tubercles in each interambulacrum (four as opposed to two or three in *P. romani*)

which have deeper scrobicules, smaller scrobicular tubercles, and situated closer to one another. Furthermore, fewer secondary tubercles are present in the interporiferous zones of the ambulacra at the ambitus in *P. raratuberculata*.

P. raratuberculata is very similar to *P. migliorinii* Maccagno (1947:118) from the Callovian-Oxfordian of Italian Somaliland. Both species are similar in having few interambulacral plates, small test, similar shape, and similar peristome. Maccagno's figure 2d (1947), however, shows the secondary tubercles in her species running down the midzone of the ambulacra immediately adjacent to each other, whereas in *P. raratuberculata* these secondary tubercles occur along the edge of the poriferous zone and are separated from each other by smaller tubercles. Unfortunately her photographs are too small to show this character and the character of the crenulation of the tubercles.

TYPE SPECIMENS.—Holotype, USNM 170384; figured paratype, USNM 170385.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, Callovian, upper Dhruma Formation, 10 meters above contact between upper and middle Dhruma at locality KK9–111.

Pseudocidaris depressa Kier, new species

FIGURE 18; PLATE 15: FIGURES 3–6; PLATE 16: FIGURES 1–4

DIAGNOSIS.—This species is characterized by its low test, wide zone of secondary tubercles separating the interambulacral tubercles, and posteriorly situated periproct.

MATERIAL.—Two well-preserved specimens.

SHAPE.—Holotype 15.2 mm in horizontal diameter, 7.4 mm high; figured paratype 12.9 in diameter, 6.9 mm high; height 48–53 percent of diameter; marginal outline circular; adapical surface gently sloping, adoral flat; interambulacra depressed along sutures; ambulacra inflated.

APICAL SYSTEM.—Preserved on both specimens; greatest length along axis passing through genital 3, ocular I, length 40 percent diameter of test in smallest specimen, 12.9 mm in diameter, 33 percent in larger, 15.2 mm in diameter; anterior genitals larger than posterior; in holotype genital plates 2, 4 meet isolating genital 3 from periproct (Figure 18A; Plate 16: figure 1), in figured paratype genital 3 not isolated

(Figure 18B); oculars II, III, IV exert in both specimens, ocular V, I insert in holotype, only ocular I insert in paratype (Figures 18); periproct displaced posteriorly, irregular in outline, wider than high.

AMBULACRA.—Slightly sinuous, at ambitus 37 percent as wide as interambulacra, maintaining same width adorally until near peristome where widening and then narrowing; inner pore of pair slightly adoral to outer, located on suture; plates simple primaries (Plate 16: figure 2) from apical system to just below ambitus; four or five compound plates in each half-ambulacrum from just below ambitus to peristome; 36 porepairs in each half-ambulacrum in specimen 12.9 mm in diameter, 39 in specimen 15.2.

INTERAMBULACRA.—Six to seven plates in each half-interambulacrum.

PERISTOME.—Diameter 48–53 percent of diameter of test, outline angular with ten sides; gill slits prominent (Plate 15: figure 4).

TUBERCULATION.—Interambulacra: single primary, perforate tubercle on each plate; crenulations not visible on adapical tubercles, pronounced on tubercles at ambitus and below; adapical tubercles low, with slightly elevated bosses, with height of bosses increasing adorally; tubercles below ambitus with high bosses with steep sides (Plate 15: figure 4); bosses extending to edge of tubercle, no scrobicule; tubercles at ambitus and above widely separated by broad areas covered with small, irregularly arranged secondary tubercles; tubercles below ambitus close together, confluent or separated only by single line of secondary tubercles (Plate 15: figure 6).

AMBULACRA.—From apical system to just below ambitus each plate bearing one larger secondary tubercle near inner pore of pair, with approximately two irregularly arranged smaller tubercles inside of it; below ambitus tubercles much larger, each covering three plates, with well-developed perforate mame-lons, high bosses, crenulations visible only on larger tubercles; these tubercles considerably smaller than interambulacral tubercles (Plate 15: figure 4).

COMPARISON WITH OTHER SPECIES.—This species is easily distinguished by its smaller primary interambulacral tubercles from *Pseudocidaris romani* Kier, new species, and *P. raratuberculata* Kier, new species, which occur high in the upper Dhruma Formation in the same measured section. It is quite similar in general appearance to *P. alhadasensis* de Loriol from the Callovian of Portugal but differs in having a

lower test, and its ambulacra less widened at the ambitus. Furthermore, in *P. depressa* the primary interambulacral tubercles are separated from one another by a far wider zone of secondary tubercles.

FIGURE 18.—*Pseudocidaris depressa* Kier, new species: A, apical system of holotype USNM 170389 from the middle Dhruma Formation at locality KK9-21-21.5 showing the separation of genital 3 from the periproct by the junction of genital plates 2 and 4, $\times 10$; B, apical system of figured paratype USNM 170390 from the middle Dhruma Formation at locality KK9-21-21.5 showing genital 4 not separated from the periproct, $\times 8$.

TYPE SPECIMENS.—Holotype, USNM 170389; figured paratype, USNM 170390.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Bathonian, middle Dhruma Formation, 80 meters below contact between middle and upper Dhruma. Locality KK9-21-21.5.

Pseudocidaris romani Kier, new species

FIGURE 19; PLATES 13, 14; PLATE 15: FIGURES 1, 2

DIAGNOSIS.—Species characterized by two or three very large crenulate primary tubercles in each interambulacrum, and in having the adoral tubercles either noncrenulate or crenulate only on the adoral side of tubercle.

MATERIAL.—Seven almost complete specimens, seven fragments.

SHAPE.—Specimens 12.4–20.0 mm in horizontal diameter, marginal outline subpentagonal with apices in interambulacra; test high with inflated apical system, height 60–65 percent of diameter; adoral surface flattened.

APICAL SYSTEM.—Preserved on five specimens; small, width 34–43 percent of diameter of test; genital plates 2, 3, 4 larger than 5, 1; all ocular plates exert (Figure 19), ocular plates IV, V, I coming nearer periproct than other oculars; periproct wider than high (as measured along line passing through genitals 1 and 4, width approximately 15 percent diameter of test).

AMBULACRA.—Sinuous, narrow, at ambitus 26 per-

FIGURE 19.—*Pseudocidaris romani* Kier, new species: apical system of the holotype USNM 170386 from the upper Dhruma Formation at locality KK9-112, $\times 8$. A photograph of this area is on Plate 14: figure 3.

cent as wide as interambulacra, continuing to widen toward peristome; inner pore of pair slightly adoral to outer; peripodia more developed adoral to ambitus; plates simple primaries (Plate 13: figure 5) from apical system to below ambitus; three or four compound plates in each half-ambulacrum from below ambitus to peristome (Plate 14: figure 2); 49 pore-pairs in each half-ambulacrum in holotype 20 mm in diameter, 48 in specimen 18.5 mm in diameter.

INTERAMBULACRA.—Five plates in each half-interambulacrum in holotype; first or second adapical plate of column very large occupying most of area of interambulacrum, almost extending across to next ambulacrum (Plate 13: figure 4).

PERISTOME.—Diameter measurable in two specimens where 50–55 percent of diameter of test; pentagonal in outline with well-developed gill slits (Plate 14: figures 1, 2).

TUBERCULATION.—Primary interambulacral tubercles at ambitus and above perforate, crenulate, scrobicules narrow, slightly depressed below general surface of test, basal terrace slightly developed on some tubercles, absent on others; boss large in diameter with straight or slightly concave sides; 13 to 15 well-developed crenulations; mamelon undercut, circular in outline; mamelon and boss 1.7 mm high on tubercle 3.9 mm in diameter; tubercles not confluent, scrobicular ring of secondary tubercles around each primary tubercle, smaller secondary tubercles covering rest of area; two or three large tubercles in each interambulacrum; no primary tubercle on first or second plate of some columns at apical system (Plate 13: figure 1); primary interambulacral tubercles near peristome (Plate 14: figure 1) reduced in size, noncrenulate or crenulate only on adoral side of each tubercle; ambulacrum adapically and at ambitus having only secondary tubercles; near apical system (Plate 13: figure 5) one tubercle on each plate, at ambitus one larger secondary and one or two smaller on each plate (Plate 14: figure 4); below ambitus large primary tubercle covering three or four plates; each half-ambulacrum with three or four of these primary tubercles, perforate, noncrenulate except for slight crenulations on some tubercles on their adoral side.

COMPARISON WITH OTHER SPECIES.—This species is referred to *Pseudocidaris*, although the lack of crenulations on some of the adoral primary tubercles suggests that the species also has affinities with *Cidaropsis*.

Pseudocidaris romani is very similar and may be conspecific with *P. migliorinii* Maccagno (1947:118) from the Callovian-Oxfordian of Italian Somaliland. Both species are similar in having few interambulacral plates, small test, similar shape, and similar peristome. Maccagno's figure 2d (1947), however, shows the secondary tubercles in her species running down the midzone of the ambulacra immediately adjacent to each other, whereas in *P. romani* these secondary tubercles occur along the edge of the poriferous zone and are separated from each other by smaller tubercles. If her drawing is correct then these species are distinct. Unfortunately, her photographs are too small to show this character.

It resembles *Pseudocidaris lutanica* de Loriol from the Kimmeridgian of Portugal but differs in having fewer and larger interambulacral tubercles. It is also quite similar to *Cidaropsis minor* (L. Agassiz) from the Bathonian of France in that both species have a similar shape, apical system, size and outline of peristome, ambulacral plate arrangement, and small number (two or three) of large interambulacral tubercles. *P. romani* differs in having strongly crenulate primary tubercles in the interambulacra at the ambitus and above.

TYPE SPECIMENS.—Holotype, USNM 170386; figured paratypes, USNM 170387–170388.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, Callovian, upper Dhruma Formation, 10–11 meters above contact between upper and middle Dhruma at Locality KK9–112, KK9–111.

Pseudocidaris species

PLATE 41: FIGURES 4, 5

Some very large spines occur in both the middle and upper Dhruma Formation. They are very similar to those that have been found associated with species of *Pseudocidaris*. None are attached to any specimens, so the identification must be tentative.

FIGURED SPECIMENS.—USNM 170513–170514.

Family PSEUDODIADEMATIDAE Pomel

Genus *Hypodiadema* Desor

Hypodiadema nanituberculata Kier, new species

FIGURE 20; PLATE 16: FIGURES 5–10; PLATE 17: FIGURES 1, 2

DIAGNOSIS.—Species characterized by low interam-

bulacral plates with 11 plates in half-interambulacrum of specimens 13.9–18.7 mm in diameter, and small primary tubercles.

MATERIAL.—Five well-preserved specimens.

SHAPE.—Horizontal diameter 13.9–18.7 mm, height 48–55 percent of diameter; marginal outline circular, side gently sloping, slightly depressed around peristome.

APICAL SYSTEM.—Moderately large, 31 percent diameter of test; genital 2, 3 largest; oculars pentagonal, all exert (Figure 20c); no suranal plates; elevated rim around circular or slightly oblique periproct; secondary tubercles on oculars, genitals (Plate 16: figure 10).

AMBULACRA.—Wide, at ambitus ambulacrum 2.6 mm wide in specimen 13.9 mm in diameter, 42 percent as wide as interambulacrum, narrowing gradually adapically, adorally from ambitus; outer pore of each pair slightly adapical to inner; 35 porepairs in each half-ambulacrum of specimen 13.9 mm in diameter, 38 in specimen 15.4 mm in diameter; porepairs in straight line except adoral to ambitus where arranged in slight arcs of three; plates trigeminate but each plate of three approximately of same size (Plate 16: figure 9); adapically middle plate of each three bears primary tubercle (Figure 20A) on adapical side, scrobicule of which extending slightly over adjacent adapical plate but not over adoral plate (Plate 16: figure 8); at ambitus primary tubercle large, extending over all three plates of each compound plate but less on adoral plate than adapical (Plate 16: figure 9); adoral of ambitus middle plate larger than others.

INTERAMBULACRA.—Not depressed along interradiial suture; plates 1.4 mm high at ambitus in specimen 13.9 mm in diameter, increasing in height adapically where 1.7 mm high in plate midway between ambitus and apical system (Plate 17: figures 1–2), then decreasing in height to apical system; 11 plates in each half-interambulacrum.

PERISTOME.—Large, diameter 50 percent diameter of test; outline circular with well-developed gill slits having elevated rims.

TUBERCULATION.—Tubercles crenulate, perforate.

Interambulacral: primary tubercle at ambitus (Plate 19: figure 2) large, situated slightly adoral on each plate; mamelon well developed, approximately 15 crenulations on parapet, boss slightly concave, oblique transversely, narrower on adoral side than on adapical; basal terrace distinct, scrobicule not de-

FIGURE 20.—*Hypodiadema nanituberculata* Kier, new species: A, ambulacrum IV near apical system of holotype USNM 170391 from the upper Dhruma Formation at locality KK9-112; B, apical system of same specimen, all $\times 13$. Photographs of this ambulacrum are on Plate 16: figures 8, 9 and of the apical system on Plate 16: figure 10.

pressed, narrow, slightly confluent; 10–15 secondary tubercles scattered irregularly outside of narrow scrobicule; primary tubercles decrease abruptly in size approximately $2/5$ distance from ambitus to apical system; in holotype first three plates in each half-interambulacrum with small tubercles.

Ambulacral: At ambitus primary tubercle, 60 percent as large as interambulacral, with well-developed mamelon, crenulated parapet, slightly oblique boss, narrow scrobicule with a few secondary tubercles in irregular ring outside scrobicule; tubercles decrease in size adapically (Plate 16: figure 8).

COMPARISON WITH OTHER SPECIES.—Of all the

species of this genus, *H. nanituberculata* resembles most *H. desoriana* (Cotteau) from the Kimmeridgian and Portlandian of France and Switzerland and *H. guerangeri* (Cotteau) from the Callovian of France. It differs from *H. desoriana* in having lower, more numerous interambulacral plates, fewer porepairs, and smaller interambulacral tubercles with smaller scrobicules. It differs from *H. guerangeri* in having less steep sides, smaller and more numerous interambulacral plates, and smaller tubercles at the ambitus and below with smaller scrobicules. It is very dissimilar to *H. gregoryi* (Currie) from the Bathonian or Callovian of British Somaliland and Jurassic of

Harrar. Its test is smaller, lower, with less steep sides, and it has lower, more numerous interambulacral plates.

TYPE SPECIMEN.—Holotype, USNM 170391.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, Callovian, upper Dhruma Formation, 10–11 meters above contact between upper and middle Dhruma at localities KK9–111, KK9–112.

Order PHYMOSOMATOIDA Mortensen

Family STOMECHINIDAE Pomel

Leioechinus Kier, new genus

Test of medium to large size, ocular plates commonly exert, no suranal; ambulacral plates diadematoid, trigeminate, first demiplates occurring in seventh to sixteenth compound plate from apical system, ambulacra not conspicuously widened adorally; gill slits well developed; tubercles noncrenulate, imperforate, primary tubercles larger than secondary, abruptly larger below ambitus.

TYPE SPECIES.—*Leioechinus namus* Kier, new species, from the Middle Jurassic (Bathonian), middle Dhruma Formation.

COMPARISON WITH OTHER GENERA.—This genus clearly belongs in the family Stomechinidae and is quite similar to *Psephechinus* Pomel from the Lower Jurassic to Lower Cretaceous, and *Polycyphus* L. Agassiz and Desor from the Middle to Upper Jurassic. It is like *Psephechinus* in having its first demiplates introduced after the seventh compound plate and in having its primary tubercles larger than the secondary, but differs in having both the ambulacral and interambulacral tubercles increasing in size below the ambitus. It is similar to *Polycyphus* in having larger adoral tubercles, but differs in having its primary tubercles larger than the secondary and in having the first demiplates not introduced until at least the seventh compound plate from the apical system as opposed to just below the ocular plates in *Polycyphus*.

Leioechinus namus Kier, new species

FIGURES 21–23; PLATES 23, 24

DIAGNOSIS.—Species characterized by small test and presence of demiplates in specimen as small as 12.5 mm in diameter.

MATERIAL.—Although 95 specimens can be referred to this species, the following description is based on 33 from the same locality and from a narrow stratigraphic interval.

SHAPE.—Smallest specimen 7.7 mm in horizontal diameter, largest 23.4, mean 17.1 (S.D. 3.7, C.V. 21.9, N=23); marginal outline circular, adapical surface gently curving (Plate 23: figures 5, 6); adoral surface slightly depressed around peristome; height of test (Figure 23A) 64.6 percent D (S.D. 3.6, C.V. 5.6, N=23).

APICAL SYSTEM.—Small, diameter 24–26 percent of diameter of test; genital plates large, genital 2 largest; ocular plates pentagonal, all exert; no suranal plates; periproct large, irregular in outline (Figure 21D; Plate 24: figure 11).

AMBULACRA.—Wide, at greatest width 19.8 percent D (S.D. 1.2, C.V. 5.8, N=23) greatest width not at ambitus, but above; narrowing from there to peristome, slightly widening in few specimens just before peristome; outer pore of pair slightly adapical to inner, more transversely elongated; porepairs arranged in arcs of three; 41 porepairs in half-ambulacrum of specimen 7.7 mm in diameter, 69 in specimen 12.3, 78 in specimen 16.7 mm, 83 in specimen 21.6 (Figure 23D); ambulacra composed of diadematoid compound plates having largest plate in middle, one smaller plate on either side (Figure 21B), occurrence of demiplates irregular, in some specimens demiplate adoralmost plate of three making up single compound plate (Figure 21B), in some specimens demiplate adapical and in others both adoral and adapical plates demiplates (Figure 21B); number of demiplates increasing with size of specimen, for example, no demiplates in three specimens 15.6, 16.1, 16.3 mm in diameter (Figure 22C) (although 2–3 demiplates in half-ambulacrum of specimen 12.5 mm in diameter), average of 6 demiplates in each half-ambulacrum of specimens 18–19 mm in diameter, and 12 in largest specimen 21.6 mm in diameter; demiplates occurring at midzone; first demiplates in seventh to sixteenth compound plate in each half-ambulacrum counting adoral from apical system; no demiplates in fifth to ninth adoralmost compound ambulacral plates counting adapically from peristome in each half-ambulacrum.

INTERAMBULACRA.—Slightly depressed along interradial suture; plates low with 12 plates in a half-interambulacrum in specimen 7.7 mm in diameter,

FIGURE 21.—*Leioechinus namus* Kier, new species: A, B, C, adapical, ambital, and adoral plate arrangement of ambulacrum of figured paratype USNM 170404 from the middle Dhruma Formation at locality KK8-35-38, $\times 15$; D, apical system of figured paratype USNM 170407 from the middle Dhruma Formation at locality KK8-30-35, $\times 12$, a photograph of this area is on Plate 24: figure 11.

FIGURE 22.—*Leioechinus namus* Kier, new species: A, B, adapical, ambital portions of ambulacrum of figured paratype USNM 170408 from the middle Dhruma Formation at locality KK8-30-35, $\times 11$; C, midzone of ambulacrum of figured paratype USNM 170407 from the middle Dhruma Formation at locality KK8-30-35 showing the lack of demiplates in this specimen, $\times 18$.

FIGURE 23.—*Leioechinus namus* Kier, new species: scattergrams showing the height of the test relative to the diameter (A), the diameter of the peristome relative to the diameter of the test (B), the number of plates in a half-interambulacrum relative to the diameter of the test (C), the number of pore pairs in a half-ambulacrum relative to the diameter of the test (D), the number of demiplates in each half-ambulacrum relative to the diameter of the test (E).

19 in specimen 18.6 mm, 22 in specimen 23.4 mm (Figure 23c).

PERISTOME.—Diameter 46 percent of diameter of test in smallest specimen, 38 percent in specimen 18 mm in diameter, 38.7 percent D in average (S.D. 2.8, C.V. 7.4, N=21) angular in outline with well-developed gill slits (Plate 24: figure 6).

TUBERCULATION.—Tubercles noncrenulate, imperforate; from apical system to just below ambitus single primary tubercle in middle (or slightly adoral of the middle) of each interambulacral plate, rest of surface of plate covered with large secondary tubercles, approximately 35 on each plate (Plate 23: figures 5, 6); on some interambulacral plates one or two secondary near adradial suture larger than others, almost as large as primary (Plate 23: figure 6); below ambitus primary tubercles enlarged, two to three times larger than adapical tubercles, one or two secondary tubercles on each plate also enlarged almost as big as primary (Plate 24: figure 6); on small specimens no secondary tubercles may be enlarged (Plate 24: figures 7–9); in ambulacra primary tubercle covering each compound plate; ambulacral tubercles small from apical system to below ambitus where increasing greatly in size and equal to size of interambulacral tubercles (Plate 23: figures 3, 4).

GROWTH.—The smaller specimens less than 10 mm in diameter, differ from the larger in having their primary tubercles more prominent (Plate 24: figures 7–9), fewer and smaller secondary tubercles, less difference in size between the adoral and adapical tubercles, no demiplates, and straighter pore zones.

COMPARISON WITH OTHER SPECIES.—*Leioechinus namus* is very similar to *L. amplus* which occurs at the same locality but higher in the section in the upper Dhruma Formation. They differ in that *L. namus* has a smaller test, which is relatively much lower than the larger specimens of *L. amplus*, and in having demiplates introduced in specimens only 12.5 mm in diameter, whereas none are present in any specimens of *L. amplus* less than 20 mm in diameter.

TYPE SPECIMENS.—Holotype, USNM 170402; figured paratypes, USNM 170403–170408.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—The specimens upon which this description is based are from the Middle Jurassic, Bathonian, middle Dhruma Formation, 30.0 to 38.0 meters above the Dhibi limestone at Locality KK8–30–35. Sixty-two other

specimens from the following localities can also be referred to this species: KK7–131 (2 meters above the Dhibi limestone); KK8–6–40.5 (8.5 to 43.0 meters above Dhibi); KK9–20–40 (83.5 to 103.5 meters above Dhibi); S–1064 (23.8–37.8 meters above Dhibi); S–1154; S–1160 (30–40 meters above Dhibi). One specimen from L–921 which Imlay (1970:D8) reports as being in the middle Dhruma, *Micromphalities* zone. The species ranges from 2 to 103.5 meters above the Dhibi. One specimen from locality S–1164 (13–32 meters below the top of the Dhibi) and several from higher in the section are slightly different in tuberculation and shape, but too few specimens are available to ascertain whether these differences are really significant or just a result of differing states of preservation.

Leioechinus amplus Kier, new species

FIGURES 24, 25; PLATE 22: FIGURES 1–7

DIAGNOSIS.—This species is characterized by its large size, up to 46 mm in diameter, high test, maximum height 83 percent of diameter and by its small tuberculation.

MATERIAL.—Thirty-one specimens, but statistics taken from twelve specimens from same locality.

SHAPE.—Smallest specimen 14.5 mm in horizontal diameter, largest 33.9, mean 26.7 (S.D. 6.5, C.V. 24.3, N=12); marginal outline circular, ambulacra slightly inflated, interambulacra slightly depressed along median suture; adapical surface gently curving (Plate 22: figure 2); adoral surface flattened, not depressed around peristome; height of test 71.2 percent D (S.D. 5.9, C.V. 8.3, N=11).

APICAL SYSTEM.—Preserved on eight specimens, small, varying from 26 percent of horizontal diameter of test in smallest specimen to 22 in specimen 25 mm in diameter, to 19 percent in largest; genital plates large, genital 2 larger than others (Figure 24A; Plate 22: figure 7); ocular plates all exert in seven specimens, oculars V and I almost insert on some specimens, ocular I insert in one specimen; no suranal plates; periproct large, irregular in outline.

AMBULACRA.—Wide, at greatest width 18.9 percent D (S.D. 0.9, C.V. 5.0, N=12); greatest width at ambitus or slightly above, narrowing toward peristome; outer pore of pair slightly adapical to inner; 62 porepairs in half-ambulacrum of smallest specimen 14.5 mm in diameter, 97 in specimen 26 mm in

FIGURE 24.—*Leioechinus amplus* Kier, new species: A, apical system of figured paratype USNM 170400 from the upper Dhruma Formation at locality KK9-112, $\times 10$; B, ambulacra at ambitus of figured paratype USNM 170401 from the upper Dhruma Formation at locality KK9-112, $\times 10$.

diameter, 125 in specimen 32.0 mm in diameter (Figure 25c), porepairs arranged in arcs of three with outermost porepair in middle plate, innermost in lower plate (Figure 24B); ambulacra composed of diadematoid compound plates having largest plate in middle, one smaller plate on each side, occurrence of demiplates irregular, in some specimens demiplate adoralmost plate of three making up compound plate, in some specimens demiplate adapical, and in others both adoral and adapical; number of demiplates increasing with size of specimen, no demiplates in specimens less than 20 mm in diameter, half-ambulacrum with 5 in specimen 23.3 mm, 9 in specimen 25.0 mm, 21 in specimen 32.3 mm; first demiplates in 11th to 15th compound plate in each half-ambulacrum counting adoral from apical system; no demiplates in 10 adoralmost compound counting adapically from peristome in each half-ambulacrum.

INTERAMBULACRA.—Slightly depressed along interradial suture; plates low with 16 plates in half-inter-

ambulacrum in specimen 14.4 mm in diameter, 21 in specimen 26 mm, 36 in specimen 41.0 mm (Figure 25c).

PERISTOME.—Diameter 34 percent of diameter of test in smallest specimen 14.5 mm in diameter, 32 percent in specimen 27.3 mm, 30 percent in largest 33.9 mm in diameter (Figure 25A); mean 33.8 percent D (S.D. 2.2, C.V. 6.4, N-9) angular in outline with well-developed gill slits (Plate 22: figure 4).

TUBERCULATION.—Tubercles noncrenulate, imperforate; from apical system to just below ambitus single primary tubercle on each interambulacral plate situated slightly toward interradsial suture; on larger specimens one enlarged secondary tubercle, almost as large as primary located between primary and adradial suture, a few plates have second enlarged secondary between primary and interradsial suture (Plate 22: figure 5); no enlarged secondaries on smaller specimens; rest of surface of interambulacral plate covered with small secondaries; below ambitus

FIGURE 25.—*Leioechinus amplus* Kier, new species: scattergrams showing the diameter of the test relative to the height (A), to the diameter of the peristome (B), to the number of porepairs in a half-ambulacrum (C), and to the number of plates in a half-interambulacrum (D).

primary tubercles enlarged (Plate 22: figure 4), one or two secondary tubercles on each plate likewise enlarged, almost as big as primary; in ambulacra

primary tubercle covering each compound plate situated near pores; ambulacral tubercles small from apical system to below ambitus where increasing

FIGURE 25—Continued

greatly in size and equal in size to interambulacral tubercles (Plate 22: figure 4); secondary tubercles much smaller than primary.

COMPARISON WITH OTHER SPECIES.—This species is referred to *Leioechinus* because of its trigeminate, diadematoïd ambulacral plates with the first demiplates occurring not until the eleventh compound plate, lack of adoral widening of the ambulacra, primary tubercles larger than secondary, and abruptly enlarged tuberculation below the ambitus. It is very similar to *L. namus*, which occurs at the same locality but lower in middle Dhurma Formation, and is probably descended from it. *L. amplus* is similar in the size and character of its peristome, number of interambulacral and ambulacral plates, and size and character of its apical system. It differs in being larger with a test averaging 26.7 mm in diameter (largest 33.9) as opposed to an average of 17.4 mm (largest 23.4) in *L. namus*. Its test is higher particularly in the larger specimens. The demiplates are introduced later in *L. amplus* for no specimens smaller than 20 mm in diameter have demiplates, whereas in *L. namus* seven specimens below 20 mm had demiplates including one only 12.5 mm in diameter. Finally, the tuberculation in *L. amplus* is smaller than in *L. namus* with both the primary and secondary tubercles being less developed (compare Plate 22: figure 5 to Plate 23: figure 5). This difference in the size of the tuberculation is not a reflection of the different size of the test in the two populations, for specimens of the same size of the two species can be distinguished by their tuberculation. Although these differences are significant enough to warrant specific differentiation, however, it must be emphasized that the two species are very similar, and we should expect to find intermediates in the intervening beds.

TYPE SPECIMENS.—Holotype, USNM 170397; figured paratypes, USNM 170398–170401.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Callovian, upper Dhurma Formation, 10–11 meters above the middle–upper Dhurma contact at KK9–111–112. One specimen was collected at this locality at 171.5 meters and one at 160.5 meters above the Dhibi, but both were float and probably had rolled down from higher in the section. One specimen came from S–1176 from the upper Dhurma Formation below the Tuwaiq Mountain Limestone, and three specimens from L–926.

Genus *Echinotiara* Pomel

Echinotiara arabica Melville

PLATE 17: FIGURES 3–5; PLATE 18: FIGURES 1–3

Stomechinus sp. Arkell, 1952:249

Echinotiara arabica Melville, 1955:393–401, 7 figs., pl. 19—Philip 1963:1110–1111

There are over 100 specimens in the collection that can be referred without doubt to this species which has been so carefully and thoroughly described by Melville that no description herein is necessary. Seven of the specimens came from the same locality as Melville's specimens and another eight from nearby. Enlarged photographs are included herein showing details not visible in the illustrations included with the original description.

COMPARISON WITH OTHER SPECIES.—Only two other species of this genus are known from the Jurassic: *E. bruni* Cotteau from the Bathonian of France and *E. somaliensis* Currie (1927) from the Bathonian of British Somaliland. *E. arabica* is easily distinguished from *E. bruni* by its lower test, and more numerous and larger secondary tubercles which adorally are almost as large as the primary tubercles (Plate 17: figure 5). *E. arabica* likewise has a lower test than *E. somaliensis* with its height only 48 percent of its diameter as opposed to 58 percent in the Somaliland species.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Lower Jurassic, Toarcian, lower Marrat Formation, 5.8–52.5 meters above base of formation. Localities S–989, S–1034, KK6–14.

Polycyphus arabicus Kier, new species

FIGURE 26; PLATES 19, 20

DIAGNOSIS.—This species is characterized by its numerous secondary tubercles (10–11 in each half-interambulacrum at the ambitus; 3–4 in each half-ambulacrum at the ambitus), and by the introduction of its first demiplates in the 12th–15th compound ambulacral plates.

MATERIAL.—Two well-preserved specimens.

SHAPE.—Horizontal diameter of holotype 20.2 mm, height 12.7 mm; paratype 24.0 mm by 15 mm; height 62 percent of diameter; marginal outline circular, adapical surface strongly inflated; adoral surface depressed around peristome.

APICAL SYSTEM.—Small, diameter only 18–22 percent of diameter of test; system star shaped with genital plates pointed into interambulacra; genital 2 larger than others; ocular plates exert; no suranal plates; periproct large, wider than high, irregular in outline (Figure 26; Plate 19: figure 7).

FIGURE 26.—*Polycyphus arabicus* Kier, new species: apical system of holotype USNM 170395 from the middle Dhurma Formation at locality KK8-46, $\times 15$.

AMBULACRA.—Wide, at ambitus 54 percent as wide as interambulacra; greatest width 4.4 mm at ambitus or slightly above, narrowing to 3.7 mm midway between ambitus and peristome, and then widening to 4.3 mm just before edge of peristome; in paratype ambulacra 41 percent as wide as interambulacra; outer pore of pair slightly adapical to inner; 108 porepairs in half-ambulacrum, in holotype 20.2 mm in diameter; 129 in paratype 24.0 mm in diameter; porepairs arranged in arcs of three with innermost porepair occurring in adoral plate of compound plate, except near peristome where porepairs crowded (Plate 19: figure 5); ambulacra composed of diadematoïd compound plates having largest plate in middle; first demiplate introduced in 12th–15th compound plate in each half-ambulacrum counting adoral from apical system with demiplates continuing until fourth to fifth compound plate from peristome; approximately 40 demiplates in each half-ambulacrum in specimen 20.2 mm in diameter; adalmost demiplate of each compound plate commonly smaller than adapical demiplate.

INTERAMBULACRA.—Very slightly depressed along interradian suture; plates low, exceedingly low at ambitus where in holotype only 0.5 mm high, widening adapically where 0.75 mm high near apical system, and widening adorally where fourth plate from peristome 1.0 mm high (Plate 20: figure 4); approximately 30 plates in each half-interambulacrum in both specimens.

PERISTOME.—Large, diameter 48–52 percent diameter of test; outline angular, pentagonal with apices in interambulacra (Plate 19: figure 3); gill slits shallow.

TUBERCULATION.—Tubercles noncrenulate, imperforate; no primary tubercles (except on first interambulacral plate near apical system); adapically, in interambulacra from apical system to ambitus, number of tubercles increasing from one (in each half-interambulacrum) at apical to seven midway between apical system and ambitus, to ten to eleven at ambitus; at ambitus tubercles in horizontal series, of same size, lacking differentiated mamelons (Plate 19: figure 6; Plate 20: figure 1); nearing peristome tubercles decrease in number to two or three, increase in size with well-developed mamelons, flush platforms, high bosses and in a few tubercles a miliary ring of granules present (Plate 20: figure 4); adapically in ambulacra number of tubercles increases adorally from one (in half-ambulacrum) near apical system to two midway between apical system and ambitus, to three or four at ambitus where tubercles of same size, arranged horizontally (Plate 19: figure 4; Plate 20: figure 2), similar in character and size to those in interambulacra at ambitus; adorally tubercles increase greatly in size with well-developed mamelons, etc., as in adoral interambulacra with only one tubercle in last four plates of each half-ambulacrum (Plate 19: figure 5).

COMPARISON WITH OTHER SPECIES.—This species can be referred with little doubt to *Polycyphus* because of its small test, lack of primary tubercles, large peristome, trigeminate, diadematoïd ambulacral plates, ambulacra which widen near the peristome, and tubercles which increase abruptly adoral to the ambitus. Mercier (1932:124) stated that the first demiplates in *Polycyphus* were introduced just below the ocular plate. However, I have studied specimens of the type species *P. normannus* Desor (see Plate 21: figures 3–7) and *P. textilis* L. Agassiz (see Plate 21: figures 1, 2) lent by Dr. Jean Roman from the Muséum National d'Histoire Naturelle. Although on

first impression demiplates appear to be present in the first ambulacral plates, study of the specimen under glycerine, which makes the sutures visible, shows that Mercier is mistaken. The first demiplate in a specimen of *P. normannus* is introduced in the sixth or seventh compound plate and in *P. textilis* in the fifth or sixth.

Polycyphus arabicus is very similar to *P. textilis* from the Late Bathonian and Callovian of France and the Callovian of Madagascar. The two species are similar in shape of the test, width of ambulacra, and both species have similar tuberculation with the same number of small tubercles arranged linearly at the ambitus. *P. arabicus* differs in having its first demiplates introduced in the 12–15 compound plate, whereas in *P. textilis* they are present in the sixth to seventh.

P. arabicus is very similar and may be conspecific with *P. drayi* Fourtau (1924:23, pl. 2: fig. 3) from the Callovian of Egypt. Unfortunately, the Egyptian species has never been well illustrated, and I have been unable to borrow specimens. It appears to have a similar tuberculation, but nothing is known of the number of porepairs in each ambulacrum or the number of interambulacral plates, and very little is known of its peristome. Until this Egyptian species is better known, the Arabian species will have to be considered as distinct.

P. arabicus is easily distinguished from *P. parvituberculatus* Kier, new species, from higher in the same measured section (upper Dhruma Formation) by its lower and far more numerous interambulacral plates, lack of primary tubercles, more numerous porepairs, and three to four tubercles in each half-ambulacrum at the ambitus as compared to only two in *P. parvituberculatus*.

TYPE SPECIMEN.—Holotype, USNM 170395; figured paratype, USNM 170396.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Middle Jurassic, Bathonian, middle Dhruma Formation, 47 meters above Dhibi limestone at locality KK8–46; 71–81 meters above Dhibi limestone member at locality KK9–10–20.

Polycyphus parvituberculatus Kier, new species

PLATE 18: FIGURES 4–8

DIAGNOSIS.—Species characterized by primary tubercles which are enlarged adorally, high interambu-

lacral plates, and two tubercles in each half-ambulacrum at the ambitus.

MATERIAL.—One well-preserved specimen.

SHAPE.—Horizontal diameter 20.0 mm, height 13.2; marginal outline circular, adapical surface strongly inflated; adoral surface slightly depressed around peristome.

APICAL SYSTEM.—Only part of two genital plates and three oculars preserved; small, diameter only 21 percent of diameter of test.

AMBULACRA.—Wide, at ambitus 55 percent as wide as interambulacra; greatest width at ambitus, 4.2 mm, narrowing to 3.4 mm midway between the ambitus and the peristome, and then widening to 3.6 just before edge of peristome; outer pore of pair slightly adapical to inner; 89 porepairs in half-ambulacrum; porepairs arranged in arcs of three (Plate 18: figure 8) with innermost porepair occurring in adoral plate of compound plate except near peristome where porepairs crowded; ambulacra composed of diadematoid compound plates having largest plate in middle; first demiplate introduced in fifth to seventh compound plate in each half ambulacrum counting adoral from apical system; sutures not clear enough to permit count of number of demiplates in each ambulacrum.

INTERAMBULACRA.—Not depressed along interradianal suture; plates 0.9 mm high at ambitus; approximately 19 plates in each half-interambulacrum.

PERISTOME.—Large, diameter 51 percent diameter of test; outline angular (Plate 18: figure 6); pentagonal with apices in interambulacra; gill slits narrow.

TUBERCULATION.—Tubercles noncrenulate, imperforate; interambulacral primary tubercles easily distinguishable only on first three or four plates adapically in each half-interambulacrum and near peristome where tubercles larger than secondaries and arranged in distinct series (Plate 18: figure 7); on rest of test interambulacral primary tubercles of same size as secondaries and can be distinguished only because they are linearly arranged (Plate 18: figure 5); each interambulacral plate at ambitus with five to seven irregularly arranged secondary tubercles; below ambitus both primary and secondary tubercles enlarged; in ambulacra one series of primary tubercles in each half-ambulacrum running along edge of poriferous zones; in ambital area (Plate 18: figure 8) each ambulacral plate with one secondary tubercle irregularly arranged of approximately same size as primary; adoral to ambitus primary tubercles en-

larged (Plate 18: figure 6); secondary tubercles absent.

TYPE SPECIMEN.—Holotype, USNM 170394.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, Callovian, upper Dhruma Formation, 11 meters above contact between middle and upper Dhruma Formation at KK9–112.

COMPARISON WITH OTHER SPECIES.—This species seems intermediate between *Polycyphus* and *Psephechinus*. According to Mortensen (1935: 501–503) *Polycyphus* has primary tubercles indistinguishable from the secondaries, the tubercles are abruptly larger adorally, and the first demiplates are present just below the ocular plate. *Psephechinus* has distinguishable primary tubercles, tubercles not largely adorally, and the first demiplates not present until the seventh to tenth compound ambulacral plate from the ocular. As described on page 58, it is not correct that the first demiplates in *Polycyphus* are present at the ocular. *Polycyphus normannus* Desor, the type species, has its first demiplates in the sixth or seventh compound plate. Therefore, the only differences between these two genera are in the character of the tuberculation: indistinguishable primary tubercles, and enlarged adoral tubercles in *Polycyphus*; distinguishable primary tubercles and tubercles not enlarged adorally in *Psephechinus*. This new Arabian species, however, has the distinguishable primary tubercles of *Polycyphus* but the enlarged adoral tubercles of *Psephechinus*. Perhaps these two genera should be lumped, or a new genus erected for the Arabian species, but it seems unwise to do either until all the species have been restudied and more learned about their chronological relationship to each other. Since the ambital primary tubercles are only distinguishable from the secondaries in the Arabian species because of their position in a straight line and not in size, this species is referred to *Polycyphus*.

P. parvituberculatus is easily distinguished and presumably not closely related to *Polycyphus arabicus* Kier, new species, which occurs lower in the middle Dhruma Formation. *P. parvituberculatus* has 19 plates in each half-interambulacrum, with plates 0.9 mm high at the ambitus, whereas the holotype of *P. arabicus*, which is approximately the same size, has 30 plates, which at the ambitus are 0.5 mm high. The primary tubercles are distinguishable in *P. parvituberculatus*, whereas they are not in *P. arabicus*, and the secondary tubercles are less linearly arranged trans-

versely, there are fewer porepairs (84 versus 108 in each half-ambulacrum), and there are only two tubercles in each half-ambulacrum at the ambitus in *P. parvituberculatus*, whereas only three or four occur in *P. arabicus*.

Order HOLECTYPOIDA Duncan

Suborder HOLECTYPINA Duncan

Family HOLECTYPIDAE Lambert

Genus *Holectypus* Desor

Holectypus phelani Kier, new species

FIGURE 27; PLATES 39, 40; PLATE 41: FIGURES 1–3

DIAGNOSIS.—Species characterized by periproct located inframarginally nearer the peristome than the posterior margin, by its peristome which is 20–22 percent of the diameter of the test and is wider than high.

MATERIAL.—Twenty-two specimens, but description based on eighteen specimens from same locality.

SHAPE.—Specimens varying in diameter from 19.4–36.1 mm, mean 30.5 (S.D. 5.2, C.V. 17.1, N=16), slightly wider than high, marginal outline circular in smaller specimens, subpentagonal in larger; test low, height 50.3 percent diameter (Figure 27) (S.D. 3.1, C.V. 6.1, N=16), test depressed around peristome.

APICAL SYSTEM.—Central, very small, width only 7.6 percent of diameter of test; wider than high; four genital pores, no pore in genital 5, genital 2 largest, genital 5 smallest, narrow; ethmophractic.

AMBULACRA.—Narrow, width 14.7 percent diameter of test (S.D. 9.0, C.V. 6.1, N=14) as wide as interambulacra at ambitus; poriferous zones very narrow, pore slightly larger adapically with incipient petals extending two thirds distance from apical system to margin; porepairs slightly oblique with outer pore of pair adapical to inner particularly adorally; pores of pair crescent shaped with large bead separating them; beads larger in incipient petals (Plate 40: figure 1); 80 porepairs in half-ambulacrum of specimen 19.3 mm long, 127 in specimen 35.6 mm; adapically and marginally all ambulacral plates primaries (Plate 40: figure 5), near peristome (Plate 39: figure 4) every third plate greatly enlarged longitudinally, transversely, bearing tubercle.

FIGURE 27.—*Holoctypus phelani* Kier, new species: scattergram showing the height relative to the diameter of the test.

INTERAMBULACRA.—Plate chevron shaped, curved adorally above margin, adapically below; 19 plates in half-interambulacrum of specimen 20.0 mm in diameter, 26 in specimen 29.7 mm, 31 in specimen 34.3.

PERIPROCT.—Inframarginal, situated nearer to peristome than to posterior margin with distance from periproct to peristome approximately one half distance from periproct to posterior margin; opening very large, longitudinal, length 26.5 percent of diameter of test (S.D. 3.0, C.V. 11.1, N=7); opening much longer than wide, width 16.0 percent D (S.D. 1.8, C.V. 11.4, N=6).

PERISTOME.—Wider than high, width 23.2 percent diameter of test (S.D. 2.3, C.V. 10.0, N=15); height 19.2 percent D (S.D. 1.4, C.V. 7.4, N=10); gill notches well developed, on one specimen (Plate 39: figure 5) high tabs present behind each notch.

TUBERCULATION.—Tubercles crenulate, perforate; in interambulacra single tubercle on each interambulacral plate on first six plates in each column beginning at the apical system (Plate 40: figure 4), from midway to the ambitus approximately six tubercles on each plate, regularly arranged transversely and longitudinally (Plate 41: figure 1), three or four

transverse rows of much smaller tubercles on each plate; tubercles increase greatly in size at margin and adorally, eight tubercles in row on each plate just adoral to margin, as plates narrow toward peristome number of tubercles decreases until only one on each of last four plates; in ambulacra tubercles sparse adapically with approximately one on each plate; at margin tubercles increase greatly in size with two rows on each half-ambulacrum; midway between margin and peristome number of rows of tubercles reduced to one in each half-ambulacrum with a tubercle occurring on every third enlarged plate.

COMPARISON WITH OTHER SPECIES.—Of all the Jurassic species of this genus, *Holoctypus phelani* has more similarity to *H. depressus* Leske reported from the Bajocian to the Callovian of Britain and western Europe. However, *H. phelani* is easily distinguished by its smaller peristome and periproct. In *H. phelani* the width of the peristome is only 20 to 22 percent of the diameter of the test, whereas in *H. depressus* it is 30 to 35 percent. Furthermore, the peristome is wider than high in *H. phelani*, whereas it is circular in *H. depressus*. The periproct in *H. phelani* is only 23–28 percent as long as the diameter of the test, whereas it is over 30 percent in *H. depressus*. Finally,

the tubercles are smaller adorally with less developed scrobicules in *H. phelani*.

TYPES.—Holotype, USNM 170437; figured paratypes, USNM 170438–170441.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—The above description is based on specimens from KK9–108–114, Upper Jurassic, Callovian, upper Dhruma Formation, 7 to 13 meters above contact between middle and upper Dhruma. Two specimens were also collected as float at KK9–95–97 which is 4 to 6 meters below this contact in the middle Dhruma, but these specimens may have rolled down from the upper Dhruma. Two specimens are from L–926 (Atash Member—upper Dhruma), and one from S–1176 (upper Dhruma).

Order CASSIDULOIDA Claus

Family CLYPEIDAE Lambert

Genus *Bothryopneustes* Fourtau

Bothryopneustes dhrumaensis Kier, new species

FIGURE 28; PLATE 33: FIGURES 1–6

DIAGNOSIS.—Species characterized by high test with greatest width posterior to center, pointed posterior with high truncation, anterior apical system, small peristome, and short petals.

MATERIAL.—Although there are twenty-two specimens in the collection that can be referred to this species, only nine, those from the same locality are used in the following description.

SHAPE.—Specimens 23.7–33.8 mm long, mean 28.2 mm, width 92.2 percent L (S.D. 3.5, C.V. 3.8, N–9); marginal outline slightly angular, greatest width posterior to center, adapical surface gently rounded, sides steep, adoral surface depressed in ambulacra; test high with height 58.4 percent L (S.D. 2.5, C.V. 4.2, N–9).

APICAL SYSTEM.—Slightly anterior to center, four genital pores, tetrabasal, ethmophractic, genital 2 largest (Figure 28A), genital 3 smallest, oculars V, I in contact with each other, located at distance from anterior margin equal to 50.0 percent L (S.D. 2.7, C.V. 5.4, N–7).

AMBULACRA.—Petals well developed, open, of approximately equal length, or anterior petal slightly longer, mean length of petal III 40.5 percent L (S.D.

FIGURE 28.—*Bothryopneustes dhrumaensis* Kier, new species: A, from the middle Dhruma Formation at locality KK8–33–35 apical system of the holotype USNM 170421, $\times 18$; B, phyllode IV of figured paratype USNM 170422 from the middle Dhruma Formation at locality KK8–30–35, $\times 16$.

1.5, C.V. 3.9, N–4); petal II 37.8 percent L (S.D. 1.4, C.V. 3.6, N–5); petal I 38.6 percent L (S.D. 3.0, C.V. 7.8, N–6); petals of equal width, mean width 11.6 percent L (S.D. 1.0, C.V. 8.8, N–5);

interporiferous zones broadening distally; poriferous zones narrowing distally, outer pore of pair slitlike, inner pore slightly elongated transversely, approximately same number of pores in each petal, in specimen 23.8 mm long 40 porepairs in each half-ambulacrum of petal; in specimen 34.2 mm long 50 porepairs in half-ambulacrum of petal III, 46 in petal II, 47 in petal I.

PERIPROCT.—Situating high on posterior truncation at top of narrow trough, opening higher than wide (Plate 33: figure 3).

PERISTOME.—Anterior, small, width 7.6 percent L (S.D. 0.7, C.V. 8.7, N=5); outline pentagonal, height equal to width; located with anterior edge of peristome at distance from anterior margin of test equal to 40.8 percent L (S.D. 1.8, C.V. 4.3, N=7).

FLOSCELLE.—Bourrelets moderately developed; phyllodes (Figure 28B) long, slightly broadened, double pored, three series of porepairs in each half-ambulacrum, approximately 10 in each inner series, 6 in middle, total of 20–23 in phyllode of half-ambulacrum III, 25–30 in other half-ambulacra; no buccal pores.

COMPARISON WITH OTHER SPECIES.—*Bothryopneustes dhrumaensis* occurs at the same locality and horizon with *B. arabica*, but it is easily distinguished from it by its narrower and higher test, less wide posteriorly, more anteriorly situated apical system, and broader petals with fewer porepairs. *B. dhrumaensis* differs from *B. orientalis*, which occurs higher in the Callovian, by its higher test which is wider posteriorly, far more pronounced posterior truncation, and shorter petals.

TYPES.—Holotype, USNM 170421; figured paratypes, USNM 170422, 170423.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Middle Jurassic, Bathonian, middle Dhruma Formation, 32.5–46.5 meters above Dhibi limestone at KK8–30–44 (type collection); 98.5–161.5 meters above Dhibi limestone at KK9–35–98; L–921 which according to Imlay (1970:8) is in the middle Dhruma *Micromphalities* or *Dhrumaites* zone; L–922, S–1045, S–1154, middle Dhruma Formation.

Bothryopneustes arabica Kier, new species

FIGURE 29; PLATE 32: FIGURE 5; PLATE 33: FIGURES 7–10

DIAGNOSIS.—Species characterized by thick test with its greatest width posterior to the center; and peri-

proct which is situated in notch high on posterior truncation.

MATERIAL.—Ten specimens.

SHAPE.—Specimens 35.4–52.0 mm long, mean 41.5 (S.D. 5.8, C.V. 13.9, N=7), test nearly as wide as long with width 94.0 percent L (S.D. 3.4, C.V. 3.6, N=7); greatest width posterior to center; test thick, height 47.4 percent L (S.D. 3.4, C.V. 7.2, N=7); posterior steep, vertical; petals flush with test; ambulacra depressed adorally; test depressed around peristome.

APICAL SYSTEM.—Central to slightly posterior, located at distance as measured from anterior margin to center of system equal to 54.1 percent L (S.D. 3.3, C.V. 6.1, N=4); tetrabasal (Figure 29A), ethmophractic, genital 2 largest, genital 3 very small; oculars V, I in contact with each other; four genital pores.

AMBULACRA.—Petals well developed, broad, of equal width, with width 9 percent L; petals long, extending over two thirds distance to margin, petal III slightly longer than others, 44.4 percent L (S.D. 0.5, C.V. 1.2, N=2), anterior paired petals slightly longer than posterior paired petals, length 40.0 percent L (S.D. 2.6, C.V. 6.5, N=4); interporiferous zones widening distally; poriferous zones narrowing distally, outer pore of pair slitlike, inner pore slightly elongated obliquely; 67 porepairs in single poriferous zone of petal III, 60 in petal II of specimen 36.8 mm long, 64 in single zone of petal II, 62 in petal I of specimen 39.7 mm long.

PERIPROCT.—Situating at top of narrow trough high on posterior truncation (Plate 33: figure 8) slightly supramarginal; opening higher than wide.

PERISTOME.—Anterior, small, pentagonal, height equal approximately to width, width 5.4 percent L (S.D. 0.3, C.V. 5.9, N=3); located at distance from anterior margin to anterior of peristome of 39.2 percent L (S.D. 1.6, C.V. 4.2, N=5).

FLOSCELLE.—Bourrelets well developed; phyllodes (Figure 29B) long, slightly broadened (Plate 32: figure 5), double pored, three series of porepairs in each half-ambulacrum, approximately 9 in inner series, 7 in middle, total of 22 to 26 porepairs in phyllode of half-ambulacrum; no buccal pores.

COMPARISON WITH OTHER SPECIES.—Although its slightly supramarginal periproct makes this species resemble some species of *Clypeus*, all its other features are typical of *Bothryopneustes*. It differs from *Bothry-*

FIGURE 29.—*Bothryopneustes arabica* Kier, new species: A, apical system of figured paratype USNM 170425 from the middle Dhurma Formation at locality KK8-35-38, $\times 15$; B, phyllode II of holotype USNM 170420 from the middle Dhurma Formation at locality KK8-35-38, $\times 10$.

opneustes orientalis Fourtau from the Callovian of Egypt, Somaliland, and Arabia in being wider posteriorly, in having a smaller periproct, more supra-marginal in position with a pronounced trough extending adorally from the opening, and in having a much smaller peristome.

It is quite similar to *Bothryopneustes galhauseni* Lambert (well illustrated in Petitot 1959, pl. 14: figs. 24–28) from the Lusitanian-Kimmeridgian of

Morocco but differs in having its greatest width posterior.

TYPES.—Holotype, USNM 170420; figured paratypes, USNM 170424–170425.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Middle Jurassic, Bathonian, middle Dhurma Formation, 37.5 to 48.5 meters above Dhibi limestone at locality KK8-35-46; L-920.

Bothryopneustes kauffmani Kier, new species

FIGURE 30; PLATES 35, 36

DIAGNOSIS.—This species is characterized by its long petals, pointed posterior, large, higher than wide peristome, phyllodes with pores arranged in arcs of three, genital plates which extend deeply into the interambulacra, and larger tubercles on adapical surface.

MATERIAL.—Seven specimens.

SHAPE.—Specimens 28.4–33.3 mm long, mean 30.4 (S.D. 2.0, C.V. 6.6, N-5), width 88.0 percent L (S.D. 1.8, C.V. 2.1, N-5) greatest width posterior to center, anterior margin blunt, posterior pointed; adapical surface gently rounded, adoral surface depressed in ambulacra; test low with height 42.5 percent L (S.D. 3.3, C.V. 7.8, N-5).

APICAL SYSTEM.—Anterior, four genital pores, tetra-basal, ethmophractic, genital 2 largest, genitals extending deeply into interambulacra (Figure 30; Plate 36: figure 1), oculars V, I in contact. System located at distance from anterior margin equal to 47.3 percent L (S.D. 1.4, C.V. 2.9, N-3).

AMBULACRA.—Petals well developed, broad, open, long, extending to margin of equal length, 47 percent L; interporiferous and poriferous zones slightly narrowing distally; outer pore of pair slitlike, inner pore slightly elongated transversely (Plate 36: figure 2), approximately same number of porepairs in each petal; in specimen 27.2 mm long 49 porepairs in half-ambulacrum of petal; in specimen 33.2 mm long 55 porepairs.

PERIPROCT.—Marginal, situated low on posterior, opening longitudinal, large, higher than wide (Plate 35: figure 4).

PERISTOME.—Anterior, large, higher than wide, width 8.3 percent L (S.D. 0.5, C.V. 6.1, N-4); opening pentagonal (Plate 36: figure 5), located at distance from anterior margin to anterior of peristome 36.7 percent L (S.D. 0.6, C.V. 1.8, N-3).

A **B**

FIGURE 30.—*Bothryopneustes kauffmani* Kier, new species: A, apical system of figured paratype USNM 170431 from the upper Dhurma Formation at locality KK9-112, $\times 12$; B, phyllode of same specimen, $\times 10$.

FLOSCELLE.—Bourrelets strongly developed (Plate 36: figure 5); phyllodes slightly widened with broad interporiferous zone and with pores concentrated in arcs of three along edge of phyllodes (Figure 30B), 22 to 25 porepairs in phyllode of each half-ambulacrum; no buccal pores.

TUBERCULATION.—Single row of larger tubercles in each half-ambulacrum, and half-interambulacrum on adapical surface; tubercles crenulate, perforate, with depressed scrobicules; within petals these tubercles occur along edge of poriferous zones (Plate 36: figure 2); in interambulacra one tubercle on each plate.

COMPARISON WITH OTHER SPECIES.—This species resembles most *B. orientalis* Fourtau from the Callovian of Arabia, Egypt, and Somaliland but differs in having a more pointed posterior, a peristome which is higher than wide, phyllodes with the pore arranged in arcs of three, and genital plates which extend deeply into the interambulacra. It differs from *B. arabica*, which occurs lower in the same section, by having a more pointed posterior, longer and wider petals, more marginal periproct lacking a sulcus, far larger and higher than wide peristome, pointed genital plates, and phyllodal pores arranged in arcs of three. It differs from *B. dhurmaensis* in having a lower test, no anal sulcus, phyllodal pores in arcs of three, longer petals, and pointed genital plates.

TYPES.—Holotype, USNM 170430; figured paratypes, USNM 170431–170432.

STRATIGRAPHIC OCCURRENCES AND LOCALITY.—Upper Jurassic, Callovian, upper Dhurma Formation, 11–12 meters above contact between middle and upper Dhurma at KK9-112–113.

Bothryopneustes inflata Kier, new species

FIGURE 31; PLATE 34; PLATE 41: FIGURE 6

DIAGNOSIS.—Species characterized by high test, narrow petals, slightly developed bourrelets, small, wider than high peristome, high posterior truncation with large periproct and lack of adapical enlarged tubercles.

MATERIAL.—Eighteen specimens.

SHAPE.—Specimens 22.8–42.2 mm long, mean 32.6 (S.D. 6.4, C.V. 19.7, N=10), width 86.2 percent L (S.D. 2.4, C.V. 2.7, N=10) greatest width posterior to center, anterior margin rounded, posterior truncated; adapical surface gently rounded with greatest height at apical system, adoral surface depressed in ambulacra, peristome slightly depressed; test high with height 53.5 percent L (S.D. 2.5, C.V. 4.6, N=10).

APICAL SYSTEM.—Central to slightly anterior, four genital pores, tetrabasal, ethmophractic, genital 2

largest, genitals extending deeply into interambulacra (Figure 31A), oculars V, I in contact; system located at distance from anterior margin equal to 48.9 percent L (S.D. 1.7, C.V. 3.4, N=8).

AMBULACRA.—Petals well developed, narrow, open, extending four fifths distance to margin, petals of approximately equal length except on several specimens where anterior petal slightly longer, petal III 42.2 percent L (S.D. 3.0, C.V. 7.1, N=8), petal II 37.5 percent L (S.D. 2.3, C.V. 6.3, N=7), petal I 39.5 percent L (S.D. 2.5, C.V. 6.4, N=8); petals of approximately equal width, width 11–12 percent L; interporiferous zones widening distally, poriferous narrowing; outer pore of pair slitlike, inner pore slightly elongated transversely (Plate 34; figure 5), approximately same number of pores in each petal; in specimen 37.7 mm long 63–69 porepairs in each poriferous zone, in specimen 28.0 mm long, 52–54 porepairs in each poriferous zone.

PERIPROCT.—Marginal, situated high on posterior truncation (Plate 41: figure 6), with slight anal sulcus leading adorally to margin; opening large, longitudinal.

PERISTOME.—Anterior, located at distance from anterior margin equal to 37 percent L (S.D. 1.5, C.V. 3.9, N=9), mean width 8.2 percent L (S.D. 1.1, C.V. 14.3, N=8); wider than high, pentagonal (Plate 34: figure 7).

FLOSCELLE.—Bourrelets slightly developed; phylloides slightly widened with porepairs arranged in arcs of three (Figure 31B), 15–20 porepairs in each half-ambulacrum with one or two less porepairs in half-ambulacrum of ambulacrum III.

COMPARISON WITH OTHER SPECIES.—*Bothryopneustes inflata* is similar to *B. kauffmani* from the same locality and horizon in having its genital plates elongated into the interambulacra, but differs in having a higher test, much narrower and shorter petals, a higher posterior truncation with the periproct situated higher on the truncation, less depressed ambulacra adorally, much less developed bourrelets, and a much smaller peristome. Furthermore, the larger adapical tubercles found in *B. kauffmani* are absent in *B. inflata*. *B. inflata* differs from *B. dhrumaensis*, which occurs lower in the middle Dhruma Formation, in having its greatest width more posterior, and in having more pores in the petals. A specimen of *B. inflata* 32.1 mm long has 63 porepairs in each poriferous

FIGURE 31.—*Bothryopneustes inflata* Kier, new species: A, apical system of figured paratype USNM 170427 from the upper Dhruma Formation at locality KK9–95–96, $\times 18$. A photograph of this area is on Plate 34: figure 6; B, phylloide of figured paratype USNM 170429 from the upper Dhruma Formation at locality KK9–112, $\times 18$.

zone, whereas a specimen of *B. dhrumaensis* 34.2 mm long has only 46–50.

TYPES.—Holotype, USNM 170426; figured paratypes, USNM 170427–170429.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Upper Jurassic, Callovian, upper Dhruma Formation, at KK9–95–112 (from 6 meters below to 11 meters above the boundary between the middle and upper Dhruma Formation. I suspect that these specimens came from the upper Dhruma. When this collection was made, the fossils were lumped together from this interval.

Bothryopneutes orientalis Fourtau

FIGURE 32; PLATE 32: FIGURE 6; PLATE 37; PLATE 38: FIGURES 1–3

Bothryopneustes orientalis Fortau, 1924:29, pl. 5: figs. 9–13.—Lambert 1931:185.—Maccagno 1947:129, fig. 3, pl. 1: figs. 12, 12a.—Kier 1962:41, pl. 9: figs. 11, 12

Seventy specimens can be referred to this species, previously known from the Callovian of Egypt and the Callovian to Oxfordian of Italian Somaliland. This species was considered by Maccagno to be a synonym of *B. somaliensis* Currie from the Callovian of British Somaliland. The two species are very similar, but the test is slightly wider in *B. somaliensis* and there are more pores in the phyllodes. On scattergrams (Figure 32) their paths of points are slightly different. I am uncertain, however, whether these differences are great enough to warrant specific differentiation.

The specimen figured by me (1962, pl. 9: figs. 11, 12) was considered to be from beds from the lower Dhruma Formation. New data show that this specimen came from the Tuwaiq Mountain Formation.

Because Fourtau had only two specimens when he described this species, he was unable to indicate the variability of the species. The following tabulation includes statistics for specimens of *B. orientalis* Fourtau from the same locality.

	Mean	S.D.	C.V.	N
Length	34.1 mm	7.8	23.1	19
Percent width of length (L)	93.9	2.2	2.3	18
Percent height of length	43.1	5.6	12.9	17
Percent distance from center of apical system to anterior margin of length of test	48.4	2.0	4.1	18

	Mean	S.D.	C.V.	N
Percent of distance of anterior edge of peristome to anterior margin of test of length of test	38.5	1.4	3.6	15
Percent length of petal of length of test				
Petal III	46.5	4.1	8.8	11
Petal II	43.5	3.7	8.5	16
Petal I	44.7	3.6	8.0	17
Percent width of petal of length of test				
Petal III	11.9	1.0	8.2	17
Petal II	13.3	—	—	19
Petal I	12.3	1.3	10.4	19
Percent width of peristome of length of test	10.5	1.6	15.0	15

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Upper Jurassic, Callovian, Tuwaiq Mountain Limestone; localities L–916, L–918, S–1800, S–1804, S–293, S–1805.

Genus *Pygurus* L. Agassiz

Pygurus (Pygurus) arabicus Kier, new species

FIGURE 33; PLATE 38: FIGURES 4–7

DIAGNOSIS.—This species is characterized by the shape of its test, which has its greatest width posterior to the center and its greatest height anterior to the apical system, and by its strongly developed bourrelets and broad phyllodes.

MATERIAL.—One specimen.

SHAPE.—Test 68 mm long, 66 mm wide, 21 mm high; anterior margin blunt, greatest width posterior to center, posterior margin pointed with straight sides extending to point of greatest width of test; adapical surface depressed between apical system and anterior margin, elevated at apical system, depressed posterior, and sides gently sloping; adoral surface flat except where depressed in ambulacra.

APICAL SYSTEM.—Anterior, 27.8 mm from anterior margin, 5.2 mm wide, wider than high; four genital pores, ethmolytic, genital 2 extending back between posterior genital plates; ocular plates V and I in contact, pore in genital 3 anterior to pore of genital 2.

AMBULACRA.—Petals broad, closed, with wide interporiferous zones, petals extending three fourths distance from apical system to margin; petal III the shortest, 15.8 mm long, petal II 26.8 mm, posterior petals longest, petal I 29.5 mm long; 60 porepairs in

FIGURE 32.—*Bothryopneustes orientalis* Fourtau. Scattergrams showing: (A) the width relative to the length in this species as compared to *B. somaliensis* Currie. Note that the test in *B. orientalis* is slightly narrower; B, the number of porepairs in a half-ambulacrum of phyllode III relative to the length in this species and *B. somaliensis*; C, the height relative to the length.

single poriferous zone of petal III, 97 in petal IV, 105 in petal V; outer pore of each pair slitlike.

PERIPROCT.—Inframarginal, located at posterior margin; opening 8.7 mm long, 5.2 mm wide.

PERISTOME.—Anterior, anterior edge of peristome 23.2 mm from anterior margin, pentagonal, 6.2 mm wide, and high.

FLOSCELLE.—Bourrelets strongly developed (Plate 38: figure 6); phyllodes deeply depressed, broad (Figure 33; Plate 38: figure 7) with porepairs arranged in three series in each half-ambulacrum; 16 porepairs in half-ambulacrum of phyllode III, 25 in phyllode IV, 29 in phyllode V; paired buccal pores.

FIGURE 33.—*Pygurus arabicus* Kier, new species: phyllode II of the holotype USNM 170436 from the upper Dhurma Formation at locality L-926, $\times 7$. A photograph of this region is on Plate 38: figure 7.

TUBERCULATION.—Adoral tubercles larger than adapical.

COMPARISON WITH OTHER SPECIES.—This species has phyllodes similar to those in *Pygurus* (*Pygurus*) *smelliei* Currie from the Callovian of British Somaliland, but differs in that its test has its greatest width posterior to the center, its petals are not as long, its periproct is more elongate longitudinally, and its test has its greatest height anterior to the apical system instead of at the apical system as in *P. smelliei*. It is easily distinguished from the other Callovian species from Somaliland, *Pygurus* (*Mepygurus*) *depressus* Agassiz, var. *somaliensis* Currie by its wide phyllodes, shorter petals, and greatest height anterior to its apical system.

TYPE.—Holotype, USNM 170436.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Jurassic, upper Dhurma Formation, Atash Member, at locality L-926.

CRETACEOUS SPECIES

Order ARBACIOIDA Gregory

Family ARBACIIDAE Gray

Genus *Goniopygus* L. Agassiz

Goniopygus superbus Cotteau and Gauthier

PLATE 42: FIGURES 1–3

Goniopygus superbus Cotteau and Gauthier, 1895:101, pl. 16: figs. 5–10.—Mortensen 1935:590

There is one specimen which is indistinguishable from this species previously known from the Senonian of Persia. The dimensions in millimeters of the specimen are:

Diameter: 18.7

Height: 10.4

Greatest diameter of apical system as measured through ocular IV and genital L: 9.1

Great width of ambulacrum: 3.2

Diameter of peristome: 8.7

Number of porepairs in ambulacrum: 88

Number of compound plates or primary tubercles in ambulacrum: 26

Number of plates in interambulacrum: 18–20.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Late Cretaceous, Campanian, lower Aruma Formation at KK9.

Order PHYMOSOMATOIDA Mortensen

Family PHYMOSOMATIDAE Pomel

Genus *Actinophyma* Cotteau and Gauthier

Actinophyma cf. *A. spectabile* Cotteau and Gauthier

PLATE 42: FIGURES 4–6

Actinophyma spectabile Cotteau and Gauthier, 1895:98, pl. 15: figs. 6–10.—Gauthier 1902:151, pl. 20: figs. 7–10.—Mortensen 1935:489, fig. 287

One specimen resembles this species known from the Senonian of Persia. It differs in having only four or five plates in each ambulacral plate, whereas Cotteau and Gauthier show six or seven in their specimen of approximately the same size. Furthermore, the Arabian specimen has deep pits in the corners of the

interambulacral plates in the interrarial sutures which are not shown in Cotteau and Gauthier's illustrations of *A. spectabile*. The Arabian specimen no doubt belongs to a new species but more specimens are needed.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Cretaceous, Campanian, Aruma Formation at locality S-286.

Order HOLECTYPOIDA Duncan

Suborder HOLECTYPINA Duncan

Family DISCOIDIDAE Lambert

Genus *Coptodiscus* Cotteau and Gauthier

Coptodiscus nomiae Cotteau and Gauthier

FIGURE 34; PLATE 42: FIGURES 7-9; PLATE 43

Coptodiscus nomiae Cotteau and Gauthier, 1895: 76, pl. 12: figs. 8-14.—Lees 1928: 606, 659, pl. 46: fig. 4

This species has been reported before from the Senonian of Iran and the Campanian of Oman. The Saudi Arabian specimens came from the Aruma Formation which also occurs in Oman and presumably the Oman specimens came from this formation.

MATERIAL.—Over thirty specimens, most of them well preserved, were collected in Saudi Arabia. Because some of these specimens show features not previously described, the species is redescribed below:

SHAPE.—Diameter varying from 8.4–38.0 mm, mean 18.8 (S.D. 7.5, C.V. 39, N-15); height 36 to 50 percent of diameter, mean 42.3 percent (S.D. 4.4, C.V. 10.5, N-14); test relatively higher in smaller specimens (Figure 34A), greatest height at apical system; marginal outline circular; adoral surface slightly concave.

APICAL SYSTEM.—Ethmophractic, with five genital plates and pores; genital 2 strongly inflated on some specimens, not on others.

AMBULACRA.—No petals, pores not larger adapically; ambulacra 17.9 percent as wide as diameter of test (S.D. 1.3, C.V. 7.0, N-15); plates all low primaries adapically, but adorally every third plate enlarged; 41 porepairs in half-ambulacrum of specimen 9.2 mm in diameter, 76 in specimen 27.8; 3.2 porepairs for every millimeter of diameter (Figure 34B); larger tubercle on every third plate covering part of adjacent plate.

INTERAMBULACRA.—14–23 plates in each area, one for each millimeter of diameter of test.

PERIPROCT.—Inframarginal, situated nearer posterior margin than peristome; elongate longitudinally, height of periproct 15 percent diameter of test (S.D. 1.5, C.V. 10.4, N-13), width 70–90 percent height of periproct.

PERISTOME.—Central, circular to slightly subpentagonal, diameter 28 percent diameter of test (S.D. 2.3, C.V. 8.3, N-12) relatively larger in smaller specimens; gill slits present but not deep (Plate 43: figure 4).

INTERNAL STRUCTURES.—Internal buttresses present

FIGURE 34.—*Coptodiscus nomiae* Cotteau and Gauthier: scattergrams of the diameter of the test relative to the height (A) and relative to the number of porepairs in a half-ambulacrum (B).

adorally, one running along each half-interambulacrum (Plate 43: figure 4).

LANTERN.—Fragments of lantern present in one specimen: lantern very erect; pyramid 3.9 mm high in specimen with diameter of 15.6 mm. Auricles ambulacral, thin (Plate 43: figure 3).

TUBERCULATION.—Ambulacral and interambulacral primary tubercles of same size, deeply scrobiculate, perforate, crenulate. Ambulacral: Adapically primary tubercle on every third plate forming row of tubercles adjacent to pore series; two to four longitudinal rows of smaller tubercles inside of rows of primary (Plate 43: figure 5); adorally tubercles increasing in size going from four rows to two nearing peristome.

Interambulacral; near apical system two rows of tubercles, increasing to six near margin, becoming irregularly arranged adorally.

Deep depressions present on test; on interambulacra deep pits in transverse sutures adapically, except near center of each plate where suture not depressed, producing longitudinal ridge extending from apical system to margin (Plate 43: figure 5); marginally pits slight or absent but strongly developed nearing peristome (Plate 43: figure 2).

REMARKS.—This species is the type species of the genus which has been previously referred to the family Holoctypidae. The discovery herein, however, that internal buttresses are present necessitate the transfer of the genus to the family Discoididae.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Upper Cretaceous, Campanian, lower Aruma Formation at KK11, KK12, S-285, S-286, S-748.

Suborder ECHINONEINA H. L. Clark

Family CONULIDAE Lambert

Genus *Globator* L. Agassiz

Globator mortenseni (Checchia-Rispoli)

FIGURES 35, 36; PLATE 44

Pyrina mortenseni Checchia-Rispoli, 1932:21, pl. 2: figs. 1-3; pl. 3: figs. 1-2

There are thirty-one specimens from Saudi Arabia that can be referred to this species known from the Maestrichtian of Tripolitania. This species was extremely well illustrated by Checchia-Rispoli, and I can see no significant differences between the Arabian

specimens and his. Checchia-Rispoli referred his species to *Pyrina* Desmoulin (believing the type species to be *Pyrina petrocoriensis* Desmoulin), but as noted by Wagner and Durham (1966:445) this species was not included in the original list of species assigned to this genus. The type species of *Pyrina* is *Nucleolites castanea* Brongniart, and *Pyrina* is a subjective synonym of *Conulus* Leske. Although *Globator mortenseni* has its porepairs arranged in arcs of three as in *Pygopyrina*, its periproct is marginal, not supra-marginal, and it is therefore placed in *Globator*. These two genera are very similar and probably do not warrant differentiation.

A thorough search involving the serial sectioning of or excavation of many specimens revealed no trace of a lantern or auricles. Although Hawkins (1934:645) reported auricles in *Globator desmoulini* (D'Archiac), these "auricles" are similar to the structures found in *Conulus* which are now considered not to be auricles (Kier 1969). I know of no echinoid with an oblique peristome which has a lantern in the adult.

The Arabian specimens are described below:

MATERIAL.—Thirty-one specimens, but only thirteen well enough preserved to be measured.

SHAPE.—Specimens 22.2 mm–32.2 mm long, mean 26.2 mm (S.D. 2.9, C.V. 11.3, N-14); width 90.6 percent L (S.D. 2.4, C.V. 2.60, N-13); marginal outline smoothly elongate to subpentagonal with greatest width anterior to center; adapical surface highly inflated, height 73.2 percent L (S.D. 4.7, C.V. 6.4, N-12), smoothly rounded, adoral surface flattened, peristome not depressed; ambulacra flush with rest of test.

APICAL SYSTEM.—Central, center of apical system located at distance from anterior margin equal to 50.9 percent L, mean percent (S.D. 2.0, C.V. 3.9, N-11); tetrabasal, ethmophract, posterior oculars in contact (Figure 35).

AMBULACRA.—Not petaloid, each of approximately same greatest width with ambulacrum III with its greatest width 14.8 percent L (S.D. 1.5, C.V. 9.9, N-10), ambulacrum II 14.8 percent L (S.D. 1.2, C.V. 7.8, N-12), ambulacrum I 14.9 percent L (S.D. 1.1, C.V. 7.7, N-12); poriferous zone narrow, uniserial except near peristome where arranged in arcs of three (Figure 36B, Plate 44: figure 7); plates trigeminate with every third plate a demiplate (Figure 36A), near peristome middle porepair of each arc of

FIGURE 35.—*Globator mortenseni* (Checchia-Rispoli): apical system of hypotype USNM 170451 from the Aruma Formation at locality KK12, $\times 15$.

three in demiplate (Figure 36B), upper porepair of each arc of three occluded in first three or four trigeminate plates of each row; approximately same number of porepairs in each poriferous zone of each ambulacra on same specimen with 112 in single poriferous zone of specimen 22.8 mm long, 118 in specimen 24.6 mm long, 121 in specimen 28.4 mm long.

PERISTOME. — Anterior, central; opening large, oblique, elongated with axis of greatest length passing through interambulacrum 3, ambulacrum I; height 17.6 percent L (S.D. 1.2, C.V. 6.9, N=9).

PERIPROCT. — Located low on posterior margin, tilted, slightly visible from below; opening very large, larger than peristome, with height greater than width, 23.4 percent L (S.D. 1.4, C.V. 5.8, N=8), occurring between plates 7–11 on one specimen in which sutures visible.

TUBERCULATION. — Irregularly arranged, slightly larger adorally.

FIGURED SPECIMENS. — USNM 170448–170451, 170508.

REMARKS. — These specimens resemble *Globator orientalis* (Cotteau and Gauthier) from the Senonian of Persia, but differ in having the periproct low on the posterior margin and visible from below, whereas in the Persian species it is high on the posterior margin and not visible from below. In none of the Arabian specimens does it occur as high as in the Persian.

It differs from *Globator ataciana* (Cotteau) from the Senonian of France and the Maestrichtian of

A

B

FIGURE 36.—*Globator mortenseni* (Checchia-Rispoli): A, ambitus of ambulacrum V of hypotype USNM 170508 from the Aruma Formation at KK12, $\times 10$; B, ambulacrum at edge of peristome of hypotype USNM 170449 from the same locality, $\times 15$.

Baluchistan (Noetling 1897:19 spells it *ataxensis*) likewise in having its periproct lower on the posterior margin.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Upper Cretaceous, Campanian, lower Aruma Formation at locality KK12.

Order CASSIDULOIDA Claus

Family CLYPEIDAE Lambert

Genus *Pygurus* L. Agassiz

Pygurus (Pygurus) yamamaensis Kier, new species

PLATE 46: FIGURES 9–11; PLATE 47: FIGURES 1–5

DIAGNOSIS.—Species characterized by deep anterior notch, high test, submarginal periproct, and peristome higher than wide.

MATERIAL.—Over one-hundred specimens but most of them crushed, or fragmentary; description based on 21 moderately well-preserved specimens from one locality.

SHAPE.—Specimens 27.0–34.8 mm long, mean 31.7 (S.D. 3.2, C.V. 10.1, N=13), width slightly less than, equal to, or slightly more than length, width 99.6 percent L (S.D. 1.8, C.V. 1.8, N=13); greatest width posterior to center, deep groove in ambulacrum III at margin, left anterior side of test more prolonged than right; marginal outline angular with posterior pointed except at posterior extremity where truncated obliquely; test high, height 46.2 percent L (S.D. 3.3, C.V. 7.1, N=11), greatest height at apical system; adoral surface pulvinate, depressed particularly in ambulacra.

APICAL SYSTEM.—Anterior, located at distance from anterior margin equal to 40.3 percent L (S.D. 1.6, C.V. 3.9, N=9), four genital pores, genital 2 much larger than other genitals, extending posteriorly separating genitals 4 and 1; oculars V and I in contact.

AMBULACRA.—Petals broad, closing, petal III slightly shorter than others, length of petal III 42.1 percent L (S.D. 2.7, C.V. 6.6, N=6), petal II 45 percent L (S.D. 3.1, C.V. 6.9, N=6), petal I 47 percent L (S.D. 2.4, C.V. 5.1, N=7); petals of equal width, width of petal III 15.8 percent L (S.D. 1.2, C.V. 7.6, N=7); 38 porepairs in single poriferous zone of petal III, 45 in other petals of specimen 27 mm long; 52, 60, 60 in respective petals of specimen 34.8 mm long; outer pore of pair greatly elongated transversely, slitlike; poriferous and interporiferous zones narrowing distally; porepairs in ambulacra beyond petals.

PERIPROCT.—Submarginal, situated on oblique posterior truncation, wider than high (Plate 47: figure 3); small periproctal plates preserved on one specimen (Plate 47: figure 2).

PERISTOME.—Anterior, located at distance from anterior margin equal to 35.2 percent L (S.D. 2.6, C.V. 7.5, N=8) pentagonal, higher than wide (Plate 47: figure 1), height 11.7 percent L (S.D. 1.5, C.V. 12.4, N=5); width of peristome 10.0 percent L (S.D. 1.2, C.V. 12.4, N=5).

FLOSCELLE.—Bourrelets (Plate 47: figure 1) strongly developed, pointed; phyllodes broad, with porepairs arranged in arcs of three; 12–13 porepairs in each half-ambulacrum of ambulacrum III, 15–16 in other ambulacra.

TUBERCULATION.—Tubercles larger adorally.

REMARKS.—The presence of periproctal plates, and spines on the bourrelets (Plate 47: figure 2) indicates that these specimens were buried immediately at death.

COMPARISON WITH OTHER SPECIES.—This species resembles most closely *Pygurus montmolini* Agassiz from the Neocomian of western Europe but is easily distinguished by its more pointed posterior, more marginally situated periproct which is higher than wide, higher peristome, and more deeply indented anterior groove.

TYPE SPECIMENS.—Holotype, USNM 170456; figured paratypes, USNM 170457–170459.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Lower Cretaceous, Neocomian (for a discussion of occurrence of this species see Powers, Ramirez, Redmond, and Elberg, 1966:D70 under *Pygurus* cf. *P. rostratus*). Yamama Formation. Localities KK1–41, L-901, L-902, L-905, L-910, L-908, KK3–45, S-1262.

Family CASSIDULIDAE Agassiz and Desor

Genus *Rhynchopygus* d'Orbigny

Rhynchopygus arumaensis Kier, new species

PLATE 45

DIAGNOSIS.—Species characterized by elongate test with greatest width posterior to center, and large peristome.

MATERIAL.—Seven specimens, but four of them crushed.

SHAPE.—Specimens 19.0–31 mm long, width 75–80 percent of length with greatest width near posterior; petals slightly inflated above general surface of test, posterior obliquely truncated, adoral surface depressed; greatest height at apical system, height 32–43 percent of length.

APICAL SYSTEM.—Anterior, four genital pores, tetra-basal.

AMBULACRA.—Petals narrow, width approximately 31 percent of length; slightly closing; petals II, IV slightly shorter than anterior and posterior petals; pores conjugate with outer pore slitlike; specimen 18.9 mm long with 27 porepairs in single poriferous zone in petal III, 22 in petal II; specimen 25.2 mm long with 34 porepairs in single zone of petal III, 33 in petal II, 40 in I; single pores in ambulacra beyond petals.

PERIPROCT.—Supramarginal, situated approximately three fourths distance from apical system to posterior margin; narrow trough extending posteriorly from opening; opening longer than wide.

PERISTOME.—Anterior, pentagonal, large, slightly wider than high (Plate 45: figure 5), width of peristome 14 percent length of test; sides of opening vertical.

FLOSCELLE.—Bourrelets (Plate 45: figure 5) vertical, only slightly convex toward peristome; phylloides widening slightly; in specimen 25.2 mm long 18 pores in phyllode III, 20 in II, 25 in I; 2–3 pores in each inner series; 5–6 sphaeridia in midzone of each phyllode (Plate 45: figure 5). Buccal pores present.

TUBERCULATION.—Tubercles enlarged adorally; naked zone adorally in interambulacrum 5.

COMPARISON WITH OTHER SPECIES.—This species is quite similar to *Rhynchopygus hori* (Fourtau 1921: 66) from the Aptian of Egypt but differs in having a broader periproct sulcus and shorter posterior petals. The two species are very similar, however, and until the type specimens have been compared, it is not possible to be certain that they represent two different species.

TYPE SPECIMENS.—Holotype, USNM 170452; figured paratype, USNM 170453.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Upper Cretaceous, Campanian, Aruma Formation, Localities KK11, and km marker 78 on Khurais-Riyadh road.

Family FAUJASIIDAE Lambert

Genus *Pygurostoma* Cotteau and Gauthier

Pygurostoma cf. *P. morgani* Cotteau and Gauthier

PLATE 46: FIGURES 1–4

Pygurostoma morgani Cotteau and Gauthier, 1895:52, pl. 8: figs. 1–5.—Kier 1962:135, fig. 117, pl. 19: figs. 1–3

There is one poorly preserved specimen which is similar to this species known from the Senonian of Persia. It differs in having a broader test and a higher than wide peristome, and no doubt represents a new species, but more specimens are needed.

TYPE SPECIMEN.—Hypotype, USNM 170454.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Cretaceous, Campanian, Aruma Formation at locality S–71.

Family PLIOLAMPADIDAE Kier

Genus *Zuffardia* Checchia-Rispoli

Zuffardia cf. *Z. cerullii* Checchia-Rispoli

PLATE 46: FIGURES 5–8

Zuffardia cerullii Checchia-Rispoli, 1933:4, pl. 1: figs. 1–4

One specimen appears to be conspecific with this species from the Maestrichtian of Tripoli. It is like this species in all respects except that its test is lower. The specimen, however, is somewhat crushed and it may have originally been as high as the Tripoli material.

TYPE SPECIMEN.—Hypotype, USNM 170454.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Upper Cretaceous, Campanian, Aruma Formation, locality S–71.

Order HOLASTEROIDA Durham and Melville

Family SOMALIASTERIDAE Wagner and Durham

Genus *Iraniaster* Cotteau and Gauthier

Iraniaster Cotteau and Gauthier, 1895:26.—Mortensen 1950:168.

Somaliaster Hawkins, 1934:53.—Maccagno 1941.—Mortensen 1950:406.—Joysey 1954.—Wagner and Durham 1966: 541

Hawkins and Maccagno did not compare *Somaliaster* to *Iraniaster*, but Joysey noted their great similarity and stated that *I. douvillei* differed from *Somaliaster* only in that "Judging from Cotteau and Gauthier's (1895) figures, the oral surface of *Iraniaster douvillei* differs from *Somaliaster*, in that the pores of ambulacra I and V are situated near the posterior border of the plates, and that both interambulacra 1 and 4 are amphiapalous" (Joysey 1954:48).

Through the kindness of Dr. J. Manivit, however, I have been able to study the type specimens of *Iraniaster douvillei* in the collections of the École des Mines at the Université D'Orsay, Orsay, France.

In both the syntypes, interambulacrum 4 is amphiapalous, whereas interambulacrum 1 is meridopalous, and the pores of ambulacra I and V are situated near the anterior border of the plates. Cotteau and Gauthier's artist was in error in his drawing of the syntype figured on their plate 5: figure 6. A new drawing of this specimen is included herein (Figure 37A). Because no photographs have ever been published of these specimens, I include (Plate 49: figures 5–8; Plate 50: figure 5) photographs of the lectotype (herein designated the specimen figured by Cotteau and Gauthier, 1895, on their plate 5: figures 1–3). I can see no difference between the type species of *Somaliaster*, *S. magniventer* Hawkins, and *Iraniaster douvillei*. Dr. Rickards, the curator of the Sedgwick Museum, Cambridge, very kindly lent me a large collection of *S. magniventer* including the types. They are similar in all respects to the types of *I. douvillei*, therefore *S. magniventer* is considered a junior synonym of *I. douvillei*, and the genus *Somaliaster* a junior synonym of *Iraniaster*.

Iraniaster affinidouvillei Kier, new species

FIGURES 37D, 39D, 44; PLATE 52: FIGURES 4–7; PLATE 53

DIAGNOSIS.—Species characterized by its high, smooth test with shallow petals and shallow anterior notch.

MATERIAL.—Thirty specimens; statistics taken from 19 specimens from same locality.

SHAPE.—Specimens 35.2–43.2 mm long (M–38.9, N–19), width 90–99 percent L, mean 94.5 percent L (S.D. 2.4, C.V. 2.6, N–17); height 67–83 percent L, mean 74.9 percent L (S.D. 3.8, C.V. 5.05, N–17) (Figure 41); test rounded with slightly sunken petals and slightly sunken anterior groove; right anterior

margin extended beyond left; greatest height of test just posterior of apical system.

APICAL SYSTEM.—Central to slightly posterior, located at distance from anterior margin of 52–61 percent L, mean 56.7 percent L (S.D. 2.2, C.V. 3.80, N–15); four genital pores, ethmophract, genital 2 separating posterior genital plates but oculars V, I in contact not separated by genital 2.

AMBULACRA.—Anterior ambulacrum (III) not petaloid, in shallow groove extending over margin to peristome, notch at ambitus with depth 2.5–3.9 percent L, with mean depth of 3.5 percent L (S.D. 0.42, C.V. 11.8, N–12), groove nearer apical system (10–20 percent distance from apical system to anterior margin) with depth 0.5–1.2 percent L, mean 0.76 percent L (S.D. 0.23, C.V. 30.1, N–12); porepairs large, most crowded (Figure 39D) near apical system where width of porepair 0.8–1.1 percent L, mean 0.98 (S.D. 0.11, C.V. 11.2, N–11); smallest outside of fasciole near margin where width of porepair 0.7–0.9 percent L, mean 0.78 percent (S.D. 0.07, C.V. 9.5, N–7); phyllode porepair with width 0.7–0.9 percent L, mean 0.8 percent L (S.D. 0.10, C.V. 11.9, N–4); 18–21 porepairs in single poriferous zone between apical system and peripetalous fasciole; total of 40–50 plates in ambulacrum III, 40 in specimen 35.2 mm long, 46 in specimen 40.3 mm long, 48 in specimen 43.2 mm long. Porepairs oblique with inner pore adoral to outer, in peripodia.

Anterior paired petals (II, IV) slightly depressed with greatest depth 0.9–2.2 percent L, mean 1.6 percent L (S.D. 0.4, C.V. 25.7, N–12); length of each petal 46–55 percent L, mean 52 percent L (S.D. 2.1, C.V. 4.14, N–16), five percent longer than posterior petals; greatest width 9.4–11.5 percent L (S.D. 0.6, C.V. 6.2, N–13), approximately same maximum width as posterior petals; posterior poriferous zone curving slightly; anterior straight, span of anterior petals 70–84 percent L, mean 78 percent L (S.D. 3.2, C.V. 4.1, N–11); 37–48 porepairs in single poriferous zone with 37 in specimen 36.0 mm long, 43 in specimen 40.3 mm long, 48 in specimen 42.5 mm long with an average of 42 for the 14 specimens in which the count could be made or 1.07 porepairs for each millimeter of length; first petaloid pores in plates 13–17; total of 102–130 plates in ambulacrum II, 102 in specimen 36.3 mm long, 110 in specimen 40.3 mm long, average of 114 in nine specimens in which count could be made.

FIGURE 37.—Adoral plate arrangement of three species of *Iraniaster*: A, *Iraniaster morgani* Cotteau and Gauthier: specimen in the Muséum National d'Histoire Naturelle in Paris from the Senonian at Goulgoul, Arkowaz, Poucht-i-Koh, Louristan (Iran), $\times 2$; B, *Iraniaster douvillei* Cotteau and Gauthier: lectotype from the Ecole National Supérieure des Mines, Paris, from the Senonian of Louristan (Iran), specimen number C 101, $\times 1.7$; C, *Iraniaster douvillei* Cotteau and Gauthier: paratype of *Somaliaster magniventer* Hawkins specimen F 152 in the Sedgwick Museum, Cambridge, from the late Senonian of British Somaliland, $\times 1.7$; D, *Iraniaster affindouvillei* Kier, new species: figured paratype USNM 170504 from the Aruma Formation in cut on Khurais to Riyadh road at the 78 km. marker, $\times 1.7$.

Interporiferous zones depressed, equal in width to single poriferous zone in anterior and posterior petals; outer pore of each pair more elongated transversely than inner, pores conjugate (Plate 52: figures 4, 5).

Posterior paired petals (V, I) slightly depressed with greatest depth 0.8–2 percent L, mean 1.3 percent L (S.D. 0.4, C.V. 25.7, N=13); length of each petal 40–50 percent L, mean 46.7 percent L (S.D. 2.5, C.V. 5.4, N=14); greatest width 9.1–11.0 percent L, mean 9.9 percent L (S.D. 0.5, C.V. 5.3, N=13); petals divergent distally; span of posterior petals 53.7–59.3 percent L, mean 56.2 percent L (S.D. 2.1, C.V. 3.7, N=12); 36–48 porepairs in single poriferous zone with 36 in specimen 36.0 mm long, 43 in specimen 42.8 mm long, 48 in specimen 42.5 mm long, with an average of 42 in 11 specimens in which count could be made or 1.08 porepairs for each millimeter of length; first petaloid pores in plates 18–20; total of 118–122 plates in ambulacrum I with 118 in specimen 40.3 mm long, 122 in specimen 38.8 mm long.

Ambulacral plates in ambulacrum III and in ambulacra beyond petals with double pores; number of phyllodal pores not clear in most specimens but approximately 4–5 in phyllode III, 9–11 in II, 6 in I; pores in peripodia with high ridge between each pore of pair. Marginally, ambulacral columns Vb, Ia only one-half width of adjoining columns Va, Ib.

INTERAMBULACRA.—Small single node present on most adapical plates forming series running toward margin; 34 plates in interambulacrum 5 in specimen 35.2 mm long, 30 in specimen 38.8 mm, 32 in specimen 42.5 mm; 24 plates in interambulacrum 1 in specimen 37.2 mm long, 21 in specimen 38.8 mm long, 23 in specimen 40.3 mm, 24 in specimen 42.5 mm; 26 plates in interambulacrum 2 in specimen 35.4 mm long, 28 in specimen 36.0 mm (all specimens in which this count could be made).

PERISTOME.—Anterior, distance from anterior edge of peristome to posterior margin of test 86–94 percent L, mean 90.7 percent L (S.D. 2.0, C.V. 2.2, N=12); opening tilted almost vertically so that opening faces anteriorly; opening small, width 9 percent L.

PERIPROCT.—Located low on posterior truncation, not visible from above; opening slightly higher than wide, height 10–14 percent L, mean 12.5 percent L (S.D. 1.3, C.V. 10.7, N=12), width 9.7–13.3 percent

L, mean 11.6 percent L (S.D. 1.1, C.V. 9.8, N=9); enclosed by interambulacral plates 5–9.

ADORAL PLATE ARRANGEMENT.—Labrum (Figure 37D) expanded at edge of peristome, narrowing and then expanding posteriorly and extending back to anterior one third of third ambulacral plate; labrum in contact posteriorly with single large sternal plate, protamphisternous (as defined by Fischer 1966:548 in Treatise); length of large sternal plate (2b on Figure 37D), 40.7–44.3 percent L, mean 42.0 percent L (S.D. 1.3, C.V. 3.1, N=8), width 26.6–29.4 percent L, mean 27.7 percent L (S.D. 0.9, C.V. 3.5, N=7); plate 2a slightly larger than succeeding plates; combined length of plates 2b and 2a 45.4–49.2 percent L, mean 47.9 percent L (S.D. 1.2, C.V. 2.5, N=6), width 32.3–35.0 percent L, mean 33.4 (S.D. 1.0, C.V. 3.0, N=6); interambulacrum 4 amphiplacous (Figure 37D) with first plate abutting against two plates, interambulacrum 1 meridoplacous with first plate abutting against single plate.

FASCIOLAE.—Peripetalous fasciole passing close around ends of petals; crossing anterior petals (II, IV) on plate 11 on single specimen in which visible; posterior petals (V, I) on plates 17–19, anterior ambulacrum (III) on plates 4 or 5; crossing interambulacrum 2 on plates 4–5, interambulacrum 1 on 5–6, interambulacrum 5 on plates 8–9; fasciole with width of 0.7–0.8 percent L, mean 0.78 percent L (S.D. 0.01, C.V. 1.6, N=2); Fasciole crossing ambulacrum III at distance from apical system equal to 54.2 percent L (S.D. 0.6, C.V. 1.1, N=2), interambulacrum 4 at 49.1 percent L (S.D. 0.9, C.V. 1.9, N=2).

COMPARISON WITH OTHER SPECIES.—This species is easily distinguished from *I. affinemorgani* which occurs with it at the same localities and stratigraphic level by its higher test (Figure 44), more anterior peristome, larger periproct, longer posterior petals, greater distance from the apical system to the fasciole in the posterior interambulacra, shallower petals and anterior notch, more porepairs in the posterior petals, and narrower porepairs in the adapical portion of the anterior ambulacrum. The means of these dimensions and the t-test of their significance are tabulated at the end of the description of *I. affinemorgani*.

Iraniaster affinidouvillei is very similar to *I. douvillei* Cotteau and Gauthier from the Senonian of Persia and *Somaliaster magniventer* Hawkins (herein considered a junior synonym of *I. douvillei*) from the Senonian of British and Italian Somaliland and Persia.

I have seen and measured two of the type specimens of *I. douvillei* (Figures 37B, 39A, 42) borrowed from the Muséum National d'Histoire Naturelle (Paris) and seventeen specimens of *Somaliaster magniventer* from the Sedgwick Museum at Cambridge, England. *I. affindouvillei* differs in having a deeper anterior notch which is 3.5 percent as deep as L as opposed to only 1.3 percent in *I. douvillei*, with a difference significant by the t-test of .01. Furthermore, the anterior petals are deeper (1.6 percent L versus 0.3) with a difference significant by the t-test of .05 and the posterior petals as deeper (1.3 percent L versus 0.2) with a difference significant by the t-test of .05.

TYPE SPECIMENS.—Holotype, USNM 170467; figured paratypes, USNM 170466, 170468–9, 170504, 170507.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Upper Cretaceous, Campanian, lower Aruma Formation, locality KK11, and Aruma cut at 78 Km marker on Khurais-Riyadh road.

Iraniaster affinemorgani Kier, new species

FIGURES 38A, 39E, 43, 44; PLATE 51; PLATE 52: FIGURES 1–3

DIAGNOSIS.—Species characterized by angular low test with deep petals and deep anterior notch.

MATERIAL.—Over one-hundred specimens but many are crushed; presence of attached spines indicates burial immediately upon death. Statistics taken from 27 specimens from the same locality.

SHAPE.—Specimens 39–60 mm long (M=47.83, S.D. 5.14, C.V. 10.7, N=27), width 90.3–95.2 percent L, mean 93.1 percent L (S.D. 1.4, C.V. 1.5, N=10) (Figure 43); height 56.9–66.0 percent L, mean 61.7 percent L (S.D. 2.52, C.V. 4.1 [Figure 44], (N=8); test angular with deeply sunken petals and anterior groove, strongly inflated interambulacra; right anterior margin extended; posterior truncated obliquely with periproct slightly visible from above; greatest height of test just posterior to apical system.

APICAL SYSTEM.—Central to slightly posterior, located at distance from anterior margin of 49.7–56.5 percent L, mean 53.0 percent L (S.D. 2.1, C.V. 4.0, N=17); four genital pores, ethmophract, genital 2 separating posterior genital plates but oculars V, I in contact not separated by genital 2.

AMBULACRA.—Anterior ambulacrum (III) not petaloid, in deep groove extending over margin to

FIGURE 38.—Adoral plate arrangement of two species of *Iraniaster*: A, *Iraniaster affinemorgani* Kier, new species: figured paratype USNM 170505 from the Aruma Formation at KK11, $\times 1.7$; B, *Iraniaster bowersi* Kier, new species: figured paratype USNM 170506 from the Aruma Formation at S-1419, $\times 1.3$.

peristome, notch at ambitus with depth of 4.7–7.0 percent L, mean 5.9 percent L (S.D. 0.6, C.V. 10.2, N=12), groove nearer apical system (10–20 percent distance from apical system to anterior margin) with depth 3.0–5.8 percent L, mean 4.2 percent L (S.D. 0.86, C.V. 20.2, N=12); porepairs large, most crowded (Figure 39E) near apical system where width of porepair 1.3–1.6 percent L, mean 1.4 percent L (S.D. 0.10, C.V. 6.9, N=13); smallest outside of fasciole near margin where width of porepair 0.5–0.9 percent L, mean 0.67 percent L (S.D. 0.14, C.V. 20.2, N=7); phyllode porepair with width 1.0–1.5 percent L, mean 1.28 percent L (S.D. 0.14, C.V. 10.9, N=9); 17–27 porepairs in single poriferous zone between apical system and peripetalous fasciole with mean of 0.47 porepairs for each millimeter of L; total of 44–61 plates in ambulacrum III, 44 in specimen 39.2 mm long, 50 in specimen 52.2 mm long, 61 in specimen 53.5. Porepairs oblique with inner pore adoral to outer, in peripodia.

Anterior paired petals (II, IV) deeply depressed with greatest depth 4.0–5.3 percent L, mean 4.6 percent L (S.D. 0.35, C.V. 7.5, N=13); length of each petal 39–48 percent L, mean 44.0 percent L (S.D. 2.6, C.V. 5.9, N=17), only three percent longer than posterior petals; greatest width 8.2–10.6 percent L, mean 9.2 percent L (S.D. 0.75, C.V. 8.1, N=14), approximately same maximum width as posterior petals; petals curve slightly anteriorly, particularly posterior poriferous zones; span of anterior petals 66–72 percent L, mean 69.3 percent L (S.D. 2.03, C.V. 2.93, N=8); 38–49 porepairs in single poriferous zone with 39 in specimen 39.2 mm long, 44 in specimen 46.2 mm long, 49 in specimen 51.4 with an average of 43 for the 16 specimens in which the count could be made or 0.88 porepairs for each millimeter of length; first petaloid pores in plates 14–17; total of 102–124 plates in ambulacrum II, 102 in specimen 40.0 mm long, 118 in specimen 52.2 mm long, average of 111 in nine specimens in which count could be made.

Interporiferous zones slightly narrower than single poriferous zone in anterior and posterior petals; outer pore of each pair more elongated transversely than inner, pores conjugate (Plate 51: figure 1).

Posterior paired petals (V, I) deeply depressed with greatest depth 3.1–4.9 percent L, mean 4.3 percent L (S.D. 0.53, C.V. 12.4, N=10); length of each petal 37–44 percent L, mean 41.1 percent L (S.D. 1.9,

C.V. 4.8, N=12); greatest width 7.1–10.0 percent L, mean 8.5 percent L (S.D. 0.79, C.V. 9.3, N=11); petals divergent distally; span of posterior petals 50–60 percent L, mean 55.7 percent L (S.D. 3.58, C.V. 6.5, N=9); 36–45 porepairs in single poriferous zone with 36 in specimen 39.3 mm long, 41 in specimen 49.5 mm long, 45 in specimen 60 mm long, with an average of 40 in 15 specimens in which count could be made or 0.81 porepairs for each millimeter of length; first petaloid pores in plates 19–22; total of 116–122 plates in ambulacrum I with 116 in specimen 39.2 mm long, 121 in specimen 52.7 mm long.

Ambulacral plates in ambulacrum III and in ambulacra beyond petals with double pores; number of phyllodal pores not clear in most specimens but approximately 4–5 in phyllode III, 9 in II, 6 in I; pores in peripodia with high ridge between each pore of pair. Marginally, ambulacral columns Vb, Ia only half width of adjoining columns Va, Ib.

INTERAMBULACRA.—Single node present on most adapical plates forming series running toward margin; 29 plates in interambulacrum 5 in specimen 39.2 mm long, 32 in specimen 52.2, 33 in specimen 52.7; 21 plates in interambulacrum 1 in specimen 39.2 mm long, 25 in specimens 49.2 and 52.2 mm long, 27 in specimen 52.7; 20 plates in interambulacrum 2 in specimen 39.2 mm long, 28 in specimen 52.2, 29 in specimen 52.7 (all the specimens in which this count could be made).

PERISTOME.—Anterior, distance from anterior edge of peristome to posterior margin of test 78.3–83.9 percent L, mean 80.9 percent L (S.D. 1.54, C.V. 1.9, N=13); opening deeply depressed into adoral surface, tilted almost vertically so that opening faces anteriorly; opening small, width 6.2–6.9 percent L on three specimens in which it could be measured.

PERIPROCT.—Located high on oblique posterior truncation, slightly visible from above; opening slightly higher than wide, height 6–9 percent L, mean 7.7 percent L (S.D. 0.95, C.V. 12.4, N=8), width 6–9 percent L, mean 7.3 percent L (S.D. 1.00, C.V. 13.7, N=7); enclosed by interambulacral plates 4–10.

ADORAL PLATE ARRANGEMENT.—Labrum (Figure 38A) expanded at edge of peristome, narrowing and then expanding posteriorly and extending back to anterior one third of third ambulacral plate; anterior border of labrum forming lip preserved on few specimens; labrum in contact posteriorly with single large sternal plate, protamphisternous (as defined by

FIGURE 39.—Ambulacrum III of species of *Iraniaster*: A, *Iraniaster douvillei* Cotteau and Gauthier, lectotype from the École National Supérieure des Mines, Paris, from the Senonian of Louristan (Iran), specimen number C 101; B, *Iraniaster morgani* Cotteau and Gauthier, specimen in Muséum National d'Histoire Naturelle in Paris from the Senonian at Goulgoul, Arkowaz, Poucht-i-Koh, Louristan (Iran); C, *Somaliaster magniventer* Hawkins (herein considered a junior subjective synonym of *Iraniaster douvillei* Cotteau and Gauthier), lectotype F 163 from the Sedgwick Museum, Cambridge, from the late Senonian of British Somaliland; D, *Iraniaster affinidouvillei* Kier, new species, figured paratype USNM 170507 from the Aruma Formation in cut on Khurais to Riyadh road at 78 km. marker; E, *Iraniaster affinemorgani* Kier, new species, holotype USNM 170462 from the Aruma Formation at KK11, all $\times 4.5$. For drawing of anterior ambulacrum of *Iraniaster bowersi* Kier, new species, see Figure 40.

Fischer 1966:548 in the Treatise), length of labrum 12–20 percent L, mean 16.3 percent L (S.D. 2.0, C.V. 12.4, N–13); large sternal plate (2b on Figure 38A) length 47 percent L (S.D. 2.21, C.V. 4.7, N–9), mean width 31 percent L (S.D. 2.31, C.V. 7.4, N–9); plate 2a far larger than succeeding plates, height of plate as measured along suture with ambulacrum V 24–36 percent L, mean 28.9 percent L (S.D. 3.25, C.V. 11.2, N–14); combined length of plate 2b and 2a 50–56 percent L, mean 52.1 percent L (S.D. 2.18, C.V. 4.2, N–10), mean width 41 percent L (S.D. 3.08, C.V. 7.4, N–8); interambulacrum 4 amphiplacous (Figure 38A) with first plate abutting against two plates, interambulacrum 1 meridoplacous with first plate abutting against single plate.

FASCIOLE.—Peripetalous fasciole passing close around ends of petals (Plate 52: figure 1); crossing anterior petals (II, IV) on plates 11–13; posterior petals (V, I) on plates 17–19, anterior ambulacrum (III) on plates 4 or 5; crossing interambulacrum 2 on plate 4, interambulacrum 1 on 5–6, interambulacrum 5 on plates 8–10; fasciole with width of 1.1–1.6 percent L, mean 1.36 percent L (S.D. 0.16, C.V. 11.9, N–6); length of 244–275 percent L, mean 259 percent L (S.D. 10.3, C.V. 3.9, N–7). Fasciole crossing ambulacrum III at distance from apical system equal to 42–50 percent L, mean 42–50 percent L (S.D. 2.1, C.V. 4.5, N–9), interambulacrum 4 at 35–41 percent L, mean 38.9 percent L (S.D. 1.81, C.V. 4.6, N–9), interambulacrum 5 at 38–46 percent L, mean 39.0 percent L (S.D. 1.88, C.V. 4.8, N–5).

COMPARISON WITH OTHER SPECIES.—Of all the species of *Iraniaster* this species most resembles *I. bowersi* also from the Aruma Formation but from different localities. It differs in having a smaller, higher, and wider test with a shorter plastron, deeper anterior ambulacrum adapically, and larger porepairs in this ambulacrum. For further details of these differences and their significance by the t-test see the description of *I. bowersi*. *I. affinemorgani* occurs at the same stratigraphic level and at the same localities with *I. affinidouvillei* from which it is easily distinguished by its lower test (Figure 44), less anterior peristome, smaller periproct, shorter posterior petals, smaller distance from apical system to the fasciole in the posterior interambulacra, deeper petals and anterior notch, fewer porepairs in the posterior petals, and wider porepairs in the adapical portion of the anterior ambulacrum. The means of these dimensions

and the t-test of their significance are recorded in the following tabulation. An F-test was run to eliminate all those characters whose variances were too high to permit a valid t-test.

I. affinemorgani is easily distinguished from *I. nodulosus* Gauthier (1902:122) from the late Senonian of Iran by its higher, narrower test with its greatest width less anterior, its deeper petals and deeper anterior groove, and its posterior petals which are divergent distally instead of straight.

	Mean percent of length of test		Significance of difference by t-test (two sided)
	<i>I. affini- morgani</i>	<i>I. affini- douvillei</i>	
Height of test	61.6	74.8	.05
Distance peristome from posterior margin	80.9	90.7	.01
Height of periproct	7.7	12.5	.05
Width of periproct	7.3	11.6	.05
Length of petals II, IV	44.0	52.3	.05
Length of ambulacrum III to fasciole	46.6	54.2	.02
Distance from apical system to fasciole in interambulacrum 4	38.9	49.1	.01
Depth of anterior notch	5.9	3.6	.01
Depth anterior petals	4.6	1.7	.001
Depth posterior petals ..	4.3	1.3	.001
Number porepairs in single poriferous zone of posterior petal	81.2	108.7	.05
Width of porepairs in ambulacrum III (adapical)	1.4	0.98	.01
Width of porepairs in phyllode	1.3	0.8	.05

I. affinemorgani is quite similar to *I. morgani* Cotteau and Gauthier from the Senonian of Persia but differs in having a deeper anterior notch whose depth is equal to 5.9 percent L versus 3.2 in *I. morgani*, deeper anterior petals (4.6 percent L versus 0.5 percent), and deeper posterior petals (4.3 percent L versus 0.5 percent) in *I. morgani*. Furthermore, the plastron is considerably different in *I. affinemorgani* with a far longer plate 2b whose length is 47 percent L as opposed to only 33 percent L in *I. morgani*. In *I. affinemorgani* plate 2a makes up part of the plastron, whereas in *I. morgani* it is not any larger than the succeeding interambulacral plates and does not make up part of the plastron (Figures 38A, 37A).

TYPES.—Holotype USNM 170462; figured paratypes 170463–170465, 170505.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Upper Cretaceous, Campanian, lower Aruma Formation, KK11; Aruma cut on Khurais to Riyadh road at 78–79 km marker.

Iraniaster bowersi Kier, new species

FIGURES 38B, 40; PLATE 54

DIAGNOSIS.—Species characterized by its large, low, narrow test, with long plastron, shallow petals and shallow anterior ambulacrum.

MATERIAL.—Nine specimens, seven well enough preserved to be measured.

SHAPE.—Specimens 50.8–82.2 mm long (M–67.54, S.D. 10.31, C.V. 15.2, N–7), width 84–89 percent L, mean 86.7 percent L (S.D. 1.80, C.V. 2.1, N–5); height 44–54 percent L, mean 48.9 percent L (S.D. 3.53, C.V. 7.21, N–6); test with depressed ambulacra, almost vertical posterior truncation, nearly flat anterior adoral surface, margin angular, sharply curved, adoral surface flat except for deeply depressed peristome, slightly inflated plastron; greatest height immediately anterior or posterior of apical system; right anterior marginal extending more anteriorly than left.

APICAL SYSTEM.—Small system located posterior of center of test at distance from anterior margin of 52–62 percent L, mean 57.8 percent L (S.D. 3.28, C.V. 5.7, N–6); four genital pores, anterior closer together than posterior; ethmophract, genital 2 separating posterior genital plates but oculars V, I in contact not separated by genital 2.

AMBULACRA. — Anterior ambulacrum (III) not petaloid, slightly sunken near apical system but groove deepening anteriorly forming deep notch at ambitus and continuing deeply depressed to peristome, notch at ambitus with depth of 5–8 percent L, mean 7.2 percent L (S.D. 1.27, C.V. 17.7, N–4); groove shallow near apical system with depth of 0.8–1.4 percent L, mean 1.1 percent L (S.D. 0.29, C.V. 26.9, N–4); porepairs large, most crowded (Figure 40) near apical system where width of porepair 0.7–1.1 percent L, mean 0.94 percent L (S.D. 0.14, C.V. 14.6, N–3); smallest outside of fasciole near margin where width of porepair 0.4–0.9 percent L, mean 0.67 percent L (S.D. 0.23, C.V. 34.1, N–3); phyllode pores largest with mean width of porepair 1.14 percent L (S.D. 0.01, C.V. 1.2, N–2); 24 porepairs in single poriferous zone between apical system and peripetalous fasciole

FIGURE 40.—*Iraniaster bowersi* Kier, new species: anterior ambulacrum III of holotype USNM 170470 from the Aruma Formation at S-1419, $\times 4.5$.

in specimen 59.8 mm long (only specimen showing this character); 55 plates in ambulacrum III of specimen 59.8 mm long, 66 in specimen 77.0 mm long.

Anterior paired petals (II, IV) depressed with greatest depth 2.6–3.5 percent L, 3.0 percent L (S.D. 0.33, C.V. 10.9, N–4); length of each petal 45–49 percent L, mean 46.6 percent L (S.D. 1.25, C.V. 2.7, N–6), 8 percent longer than posterior petals; greatest width 7–9 percent L, mean 8.7 percent L (S.D. 0.49, C.V. 5.6, N–6); petals curve

FIGURE 41.—*Iraniaster morgani* Cotteau and Gauthier: Apical system of specimen in Muséum National d'Histoire Naturelle in Paris from the Senonian at Goulgoul, Arkowaz, Poucht-i-Koh, Louristan, Iran, $\times 13$. The madreporic pores are not shown.

FIGURE 42.—*Iraniaster douvillei* Cotteau and Gauthier: apical system of the lectotype from the École National Supérieure des Mines, Paris, from the Senonian of Louristan (Iran), specimen number C 101, $\times 13$.

anteriorly, particularly posterior poriferous zones; span of anterior petals 64–70 percent L, mean 67.6 percent L (S.D. 1.69, C.V. 25, N=5); 45 porepairs in single poriferous zone of specimen 50.8 mm long, 63 in

FIGURE 43.—*Iraniaster affinemorgani* Kier, new species: scattergram showing the width of the test relative to the length.

FIGURE 44.—Scattergram showing the length relative to the height in *Iraniaster affinemorgani* Kier, new species, and *Iraniaster affinedouvillei* Kier, new species.

specimen 77.0 mm long with mean ratio of 0.84 porepairs for each millimeter of length of test; first petaloid pores in plates 16 or 17, 136 plates in specimen 59.8 mm long (only specimen in which full count could be made).

Interporiferous zone slightly wider than poriferous zone in anterior and posterior petal; pores conjugate.

Posterior paired petals (V, I) depressed with greatest depth 2.3–3.5 percent L, mean 2.9 percent L (S.D. 0.46, C.V. 15.4, N=5); length of each petal 37–41 percent L, mean 38.6 percent L (S.D. 1.63, C.V. 4.2, N=6); greatest width 6.7–7.8 percent L, mean 7.5 percent L (S.D. 0.40, C.V. 5.4, N=5); petals divergent distally; span of posterior petals 45–50 percent L, mean 47.1 percent L (S.D. 2.82, C.V. 5.9, N=4); 45 porepairs in single poriferous zone of specimen 50.8 mm long, 54 in specimen 77.0 mm long with mean ratio of 0.8 porepairs for each millimeter of length of test, 0–10 fewer porepairs (mean 5) in each poriferous zone than in anterior petal; first petaloid pores in plates 21–23; 141 plates in specimen 59.8 mm long, 151 in specimen 74.0 mm long (only two specimens in which full count could be made).

Ambulacral plates in ambulacrum III and in ambulacra beyond petals with double pores; number of phyllodal pores not clear in most specimens but approximately 5 in phyllode III, 10 in II, 8 in I; pores in peripodia with high ridge between each pore of pair; mean width of adoral ambulacra V or I as measured at midlength between peristome and posterior margin 12 percent length of test. Marginally, ambulacral columns Vb, Ia only one half width of adjoining columns Va, Ib.

INTERAMBULACRA.—Single node present on most adapical plates forming series running toward margin; 34 plates in interambulacrum 5, 24 in interambulacrum 1 on specimen 59.8 mm long (only specimen where all plates discernible).

PERISTOME.—Anterior, distance from anterior edge of peristome to posterior margin of test 81–85 percent L, mean 83.6 percent L (S.D. 2.08, C.D. 2.5, N=5); opening depressed deeply into adoral surface, tilted almost vertically so that opening faces anteriorly; width greater than height, mean width 6.6–7.8 percent L with mean of 7.3 in four specimens with mean length of 62.9 mm.

PERIPROCT.—Located high on broad posterior truncation which tilts 10–15 degrees from the vertical toward apical system resulting in opening partially visible from above; shape of opening variable, in some specimens higher than wide, in others wider than high, mean width 9.57 percent L (S.D. 0.60, C.V. 6.3, N=3), mean height 9.57 percent L (S.D. 1.2, C.V. 1.2, N=3); periproct enclosed within interambulacral plates 4–9.

ADORAL PLATE ARRANGEMENT.—Labrum expanded at edge of peristome, narrowing posteriorly extending back to anterior to posterior third of third ambulacral plate (Figure 38B); lip preserved on only one specimen (Plate 54: figure 6); length of labrum 11–14 percent L, mean 13.0 percent L (S.D. 0.98, C.V. 7.6, N=4); labrum in contact with single large sternal plate, protamphisternous, mean length of this plate 53 percent L (S.D. 0.44, C.V. 0.8, N=2), mean width 31.9 percent L (S.D. 0.35, C.V. 1.08, N=2); plate 2a (Figure 38B) much smaller than 2b but far larger than succeeding plates, mean height of plate as measured along suture with ambulacrum V 24.9 percent L (S.D. 1.10, C.V. 4.4, N=2); mean combined length of plate 2b and 2a 58.4 percent L (S.D. 1.20, C.V. 2.1, N=2), mean width 38.6 percent L (S.D. 0.73, C.V. 1.9, N=2); interambulacrum 4 amphiplacous with first plate abutting against two plates, interambulacrum 1 meridoplacous with first plate abutting against single plate.

FASCIOLE.—Peripetalous fasciole passing close around ends of petals, (Plate 54: figure 5); crossing anterior petals (II, IV) on plates 13–15; posterior petals (V, I) on plates 19–20, anterior ambulacrum (III) on plates 4 or 5; crossing interambulacrum 2 on plate 4, interambulacrum 1 on 6a, 5b, interambulacrum 5 on plates 8–10; fasciole wide with mean width of 1.09 percent L (S.D. 0.17, C.V. 15.3, N=4); mean length of 270 percent L (S.D. 13.79, C.V. 5.1, N=3); smallest specimen, 50.8 mm long with fasciole with average width 0.65 mm, length 130 mm, specimen 74.0 mm long with fasciole 0.80 mm wide, 214 mm long (because of the poor preservation of most of the fasciole, these figures are only estimates).

Fasciole crossing ambulacrum III at distance from apical system equal to 48.3 percent L (S.D. 1.86, C.V. 3.8, N=2), interambulacrum 4 at 36.7 percent (S.D. 0.53, C.V. 1.4, N=4), interambulacrum 5 at 36.3 percent (S.D. 2.65, C.V. 7.3, N=3).

COMPARISON WITH OTHER SPECIES.—Of all the species of *Iraniaster*, *I. bowersi* resembles most *I. affinemorgani*, also from the Aruma Formation but from different localities. *I. bowersi* differs in having a longer test with a mean length of 67.5 mm versus 47.8 with a difference significant by the t-test of 0.2; a narrower test with a mean width 86.7 percent of L versus 93.1 percent, with a difference significant by the t-test of .02, and a lower test with a mean height 48.9 percent L versus 61.7 with a difference

significant by the t-test of .02. The plastron in *I. bowersi* (plate 2b) is longer with a mean length 53.6 percent L versus 47.1 (see Figures 38A,B) with a difference significant by the t-test of .05. The combined length of plates 2b and 2a is also longer with a mean length 58.4 percent L in *I. bowersi* versus 52.1 in *I. affinemorgani* with a difference significant by the t-test of .05. The anterior ambulacrum is shallower near the apical system (as measured 10–20 percent the distance from the apical system to the anterior margin) with a depth 1.1 percent L versus 4.2 in *I. affinemorgani* with a difference significant by the t-test of .01. Finally, the porepairs in the anterior ambulacrum between the apical system and the peripetalous fasciole are smaller with a width equal to 0.9 percent L versus 1.4 percent in *I. affinemorgani* with a difference significant by the t-test of .01. An F-test was run on all these differences to be certain that the differences in the variances were not too great to permit a t-test.

TYPES.—Holotype, USNM 170470; figured paratypes, 179471, 170506.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Upper Cretaceous, Campanian, lower Aruma Formation, S-289, approximately 6 meters above base of formation; S-290, approximately 36 meters above base of formation; S-291, approximately 40 meters above base of formation, S-1234, 10–72 meters above base of formation; S-1419.

Order SPATANGOIDA Claus

Suborder HEMIASTERINA Fischer

Family SCHIZASTERIDAE Lambert

Genus *Proraster* Lambert

Proraster granti Kier, new species

FIGURE 45; PLATE 47: FIGURES 6, 7; PLATE 48

DIAGNOSIS.—Species characterized by flexuous petals, small posterior petals, greatly reduced anterior poriferous zones in each petal, and overhanging posterior truncation.

MATERIAL.—Two well-preserved specimens.

SHAPE.—Test of smaller specimen 18.5 mm long, 17.9 mm wide, 12.2 mm high; larger specimen 23.5 mm long, 22.8 mm wide, 13.1 mm high (slightly

crushed); greatest width anterior to center, width 96 percent of length; marginal outline angular, slightly indented at anterior, 0.6 mm in larger specimen, 0.4 in smaller, expanded at left anterior; posterior truncation overhanging; greatest height near posterior, on smaller specimen height 65 percent of length of test.

APICAL SYSTEM.—Posterior, distance from apical system to anterior margin 64–70 percent length of test, tetrabasal, four genital pores, ethmolytic (Figure 45c; Plate 48: figure 5), wider than high, 1.92 mm wide in larger specimen.

AMBULACRA.—Anterior ambulacrum not petaloid, in deep groove adapically (1.4 mm deep in larger specimen, 0.85 mm deep in smaller), groove shallower at margin (0.6 mm deep in larger specimen, 0.4 in smaller), and slightly deepening nearing peristome where 0.8 mm deep in larger specimen, 0.35 in smaller; porepairs very small near apical system but becoming very large and chevron shaped near mid-length between apical system and peripetalous fasciole (0.63 mm wide in largest specimen, 0.43 in smaller) and then becoming abruptly smaller in third or fourth plate in each column before fasciole (Figure 45B) where only 0.18 mm wide in larger specimens; 32–34 porepairs between apical system and fasciole; porepairs increase in size in phyllode where 0.30 mm wide in largest specimen; median (perradial) suture sinuous adapically (Figure 45B).

Anterior paired petals highly flexuous, length equal to 42–46 percent length of test, greatest width three quarters distance from apical system to end of petal, width 10–11 percent length of test; porepairs highly elongated transversely, porepairs of anterior poriferous series greatly reduced in size (Figure 45c; Plate 48: figure 6) except near distal end of petal; 26 porepairs in single poriferous zone in smaller specimen (18.5 mm long), 33 in specimen 23.5 mm long (ratio of 1.4 porepairs for each mm of length of test); petals depressed with greatest depth in largest specimen 0.6 mm (2.5 percent of length of test), in smaller 0.3 mm (1.6 percent); span of petals 13.2 mm on larger specimen, 10.2 on smaller (55–56 percent length of test).

Posterior paired petals strongly divergent, subtending angle of 130 degrees, short, only one fifth as long as anterior petals, length 9 percent length of test; width 6 percent length of test; porepairs highly elongated transversely, porepairs of anterior poriferous

FIGURE 45.—*Proraster granti* Kier, new species: A, adoral plate arrangement, $\times 4$; B, anterior ambulacrum III, $\times 5$; C, apical system, all of the posterior petals, $\times 13$; D, extremity of petal V showing greatly constricted area just beyond petal, $\times 13$. Holotype USNM 170461 from the Aruma Formation at locality S-748.

series greatly reduced in size (Figure 45c) except near distal end of petal; 8 porepairs in single poriferous zone in specimen 18.5 mm long, 9 in specimen 23.5 mm (ratio of 4.3 to 3.8 porepairs for each mm of length of test respectively); petals slightly depressed with greatest depth in largest specimen approximately 0.4 mm (1.6 percent length of test), span of petals 4.2 mm in larger specimen, 3.1 in smaller (17 percent of length of test).

Pores in ambulacral plates beyond petals double in some plates, but in others single slit suggesting two former pores joined into one; ambulacra greatly constricted where fasciole crosses just beyond petals (Figure 45d); marginally ambulacral columns Vb, Ia narrower than adjoining columns Va, Ib.

Ambulacrum I with 53 plates in large specimen (number not clear in smaller), ambulacrum II with 88 plates in large specimen, 73 in small, ambulacrum III with 44 plates in both large and small specimen.

INTERAMBULACRA.—Larger specimen with 17–18 plates in interambulacrum 5, 16 in 1, 31–33 in 2.

PERISTOME.—Anterior, distance from anterior edge of peristome to posterior margin of test 76 to 84 percent of length of test; width of peristome 10–12 percent length of test, height 60 percent of width of peristome; opening tilted toward anterior.

PERIPROCT.—High in posterior truncation, slightly visible from above; opening higher than wide, height 10 percent of length of test; width 75–78 percent of height of periproct; enclosed by interambulacral plates 6a, 7a, 5b, 6b.

PERIPETALOUS FASCIOLAE.—Well developed, passing close to ends of petals, across ambulacrum III at distance from apical system equal to 59, 60 percent length of test, interambulacrum 4 at 17, 28 percent, interambulacrum 5 at 10, 12 percent; widest at tip of and anterior to anterior petals where 1.1 mm wide in larger specimen, 6.5 in smaller, narrowest in interambulacra 1, 4 where 0.3 mm in larger specimen 0.2 in smaller, at tips of posterior petals 0.7 mm wide in larger, 0.5 in smaller, at anterior ambulacrum 0.6 mm wide in larger, 0.5 in smaller; fasciole approximately 56 mm long in larger specimen, 44 in smaller; crossing ambulacrum III on plate 5a, 4b; ambulacrum II on 10 or 11a, and 11b; ambulacrum I on 17a, b (only visible on one specimen); interambulacrum 2 on plate 3 or 4 (not certain on either specimens); interambulacrum 1 on 6a, b; interambulacrum 5 on plate 9a, b.

ADORAL PLATE ARRANGEMENT.—Plastron amphisterous; labrum extending back two thirds length of second ambulacral plate, length 15, 17 percent of length of test; plastron wider than high, composed of two equal-size plates with length 44, 53 percent of length of test, combined width 50 percent of length of test (only measurable on larger specimen); interambulacra 4, 1 separated from peristome by junction of adjacent ambulacra (Figure 45A); interambulacrum 4 amphiplacous with first plate abutting two plates, interambulacrum 1 meridoplacous in one specimen with first plate abutting against single plate, but barely amphiplacous in other specimen with first plate barely touching second plate (Figure 45A).

TUBERCULATION.—Tubercles largest adorally particularly in anterior portion of plastron and first plates of other interambulacra.

TYPE SPECIMENS.—Holotype, USNM 170461; figured paratype, USNM 170460.

COMPARISON WITH OTHER SPECIES.—This species most resembles *Proraster morgani* (Cotteau and Gauthier, 1895:43, pl. 7: figs. 6–9) from the Senonian of Persia. It differs from this species in having its posterior truncation overhanging instead of tilted. The anterior groove in *P. granti* appears to be narrower, the anterior petals less divergent, and the greatest width of the test more anterior. The specimen that Gauthier (1902:142, pl. 20: fig. 18) referred to *P. morgani*, also from the Senonian of Persia, is even more similar to *P. granti*, having its test with its greatest width more anterior as in *P. granti* and its anterior petals with the same divergence. Unfortunately, Gauthier does not show a side view of this specimen, so I can not know whether its posterior is overhanging as in *P. granti* or the reverse as in the type specimens of *P. morgani*. The two species are very similar, however, and *P. granti* may not be a separate species, but more specimens are needed before a more definite determination can be made.

STRATIGRAPHIC OCCURRENCES AND LOCALITIES.—Upper Cretaceous, Campanian, Aruma Formation; locality S-748.

REMARKS.—One of the most interesting features of this species is the fact that the pores beyond the petals seem to be transitional between the double-pore and single-pore condition. Most pre-Tertiary spatangoids have two pores in each ambulacral plate beyond the petals, whereas most post-Cretaceous species have a single pore (Kier 1962:5). This species has some

plates with double pores but some in which the two pores are joined together producing a narrow slit. This structure is transitional between the two- and one-pore condition and occurs at the time (in the late Late Cretaceous) when these transitional forms would be expected.

The ambulacra just immediately beyond the petals where the fasciole crosses are greatly constricted in this species (Figure 45D), recalling a similar condition found in the living species *Hemiaster expergitus* Lovén.

LIVING HABITS.—The morphology of this species suggests that it lived buried or partially buried in the sediment. The cilia in the peripetalous fasciole would have produced currents of water directed across the respiratory tube feet in the petals, assuring the echinoid of a sufficient supply of oxygen in its burrow. The fasciole is particularly wide indicating that these currents were strong. Nichols (1959:361) has shown that the strength of the fasciole current is roughly proportional to the thickness of the fasciole. The depression of the petals would also aid in the flow of currents across these tube feet.

The large chevron porepairs in the anterior ambulacrum indicate that large penicillate tube feet protruded from them. These tube feet are used in recent spatangoids to build a funnel to the surface and to plaster mucus over the walls of this funnel in order to keep it open so that oxygenated water can be drawn down it. Nichols (1959a:70) claimed that these tube feet, in *Echinocardium cordatum* (Pennant), are used only for this purpose and not for food gathering as previously thought. Buchanan (1966:111), however, observed these tube feet selecting sand grains which eventually found their way into the gut, and he concluded that the tube feet were used for both funnel building and food gathering. Likewise, Chesher (1963:570) has shown that in the spatangoid *Moiria atropos* (Lamarck) the tube feet, after they have excavated the funnel, extend to the surface and rake nutrient-rich debris into the burrow where it is consolidated into a mucus rope and passed to the mouth.

TERTIARY SPECIES

Order TEMNOPLEUROIDA Mortensen

Family TEMNOPLEURIDAE A. Agassiz

Genus *Opechinus* Desor

Opechinus costatus (d'Archiac and Haime)

FIGURE 46; PLATE 57: FIGURES 2-5; PLATE 58; PLATE 59: FIGURE 1

Temnopleurus costatus d'Archiac and Haime, 1853:204, pl. 13: figs. 9a,b.—Duncan and Sladen 1883:77, 84, pl. 13: figs. 9, 10

Opechinus costatus (d'Archiac and Haime), Mortensen, 1943:303, pl. 21: fig. 5

A large collection of Arabian specimens appears to be indistinguishable from this species previously known from the Miocene of Kattywar. Although I have not been able to obtain any Kattywar specimens for a direct comparison, Duncan and Sladen's illustrations are excellent, and I can see no differences between the Arabian and Kattywar specimens. Duncan and Sladen reported four species of *Opechinus* from the Miocene of Kattywar: *O. rousseaui* (d'Archiac), *O. tuberculosus* (d'Archiac and Haime), *O. costatus* (d'Archiac and Haime), and *O. affinis* (Duncan and Sladen) all from the same locality. I doubt that these species are all distinct. There is considerable variation in the sculpturing in the Arabian population, with specimens which have sculpturing similar to all of these Kattywar species. For example, the sculpturing in one of the Arabian specimens (Plate 57: figure 4) is identical to that in Duncan and Sladen's *O. affinis*. Duncan and Sladen (1883:77) stated that they believed *T. rousseaui* and *T. costatus* were synonymous, but later in the same work (1883:84) the two were considered as separate species. Although I believe that these species are probably synonymous, I have not seen any of the non-Arabian specimens and therefore hesitate to synonymize them.

A description of the Arabian specimens is given below:

MATERIAL.—A total of 75 specimens, but the following description is based on 51 specimens from the same locality (S-360), 33 of which were measured.

SHAPE.—Specimens 6.2–15.5 mm long (M-10.6, S.D. 2.2, C.V. 20, N-33), mean height 63.1 percent of diameter of test (S.D. 9.6, C.V. 15.2, N-33).

APICAL SYSTEM.—Greatest diameter (commonly passing through genital 2 or 3) 30.4 percent of diameter of test (S.D. 5.0, C.V. 16.5, N-19); periproct large, greatest diameter (extending through genital 3 and ocular I) 15.8 percent diameter of test (S.D. 3.2, C.V. 20.7, N-9) with opening situated eccen-

FIGURE 46.—*Opechinus costatus* (d'Archiac and Haime): A, apical system of USNM 170478 from the Dam Formation at locality S-360, $\times 13$; on this specimen ocular I is insert; B, apical system of hypotype USNM 170480 from the same locality showing a specimen in which ocular I is exert, $\times 13$; C, Ambulacral plate at ambitus of hypotype USNM 170503 from the same locality, $\times 20$.

trically toward genital 5 or ocular I; no suranal plates; genital plates extending into interambulacra at interr radial suture opposite genital pores (Figure 46A; Plate 59: figure 1), genital 2 elevated at madreporic pores; tubercles or nodes on genital, ocular plates; 11 specimens with apical system preserved, in 10 of them all oculars exert with oculars V, I entering farthest toward periproct (Figure 46B), in one specimen ocular I insert (Figure 46A).

AMBULACRA.—Greatest width of ambulacrum at ambitus where 24.0 percent diameter of test (S.D. 4.4, C.V. 18.2, N-33), not expanding at peristome; compound plates of echinoid type with adoral plate (Figure 46c) largest, middle plate smallest (demi), upper plate narrow but extending from adradial to perradial sutures; porepairs arranged in arcs of three with middle pair situated farthest away from perradial suture, adoral pair indented most toward perradial suture (Plate 58: figure 5); 23 porepairs in single poriferous zone of smallest specimen 6.2 mm in diameter, 55 in largest, average of 4 porepairs for every millimeter of diameter; 3.5 ambulacral plates for each interambulacral plate at ambitus in large specimens.

INTERAMBULACRA.—Width of each area at ambitus 35.4 percent diameter of test (S.D. 5.5, C.V. 15.5, N-33); height of plate at ambitus in large specimen approximately 50 percent of width; 19 plates in both columns of interambulacrum in smallest specimen 6.2 mm in diameter, 36 in largest.

PERISTOME.—Diameter 43.4 percent of diameter of test (S.D. 5.9, C.V. 13.6, N-31); test slightly depressed around opening; gill slits moderately developed (Plate 57: figure 2), 2 mm deep in specimen 11.2 mm in diameter.

TUBERCULATION.—Single primary crenulate imperforate tubercle on each ambulacral, interambulacral plate forming a vertical series; not arranged in horizontal series adorally; commonly three secondary tubercles on each ambulacral plate with pair situated immediately adapical to primary tubercle, and third situated adapically and more medially from primary tubercle (Plate 58: figure 5). Interambulacrum with primary tubercle in middle of plate but eccentrically adoral, pair of secondary tubercles immediately adapical to primary tubercle (Plate 58: figure 6), commonly a single larger secondary tubercle on either side of primary and slightly adapical to it, 4-6 other tubercles irregularly arranged over rest of each plate;

on some specimens (Plate 57: figure 5) horizontal row of pits along transverse suture decreasing in size away from large central pair of pits.

PLATE SCULPTURING.—Ambulacra with two vertical, alternating rows of deep pits or depressions in each area (Plate 58: figure 5), these deep pits occurring in corners of perradial suture; one or two smaller pits present on each plate near base of primary tubercle on median side of tubercle. Interambulacrum with four vertical rows of deep pits or depressions (Plate 58: figure 6), these pits occurring on transverse suture, adorally situated on either side of primary tubercle; four or five other smaller pits on each plate, one small pit commonly between the two larger pits, two or three near the interrarial suture and a larger one at each corner of the interrarial suture; a narrow ridge commonly vertically joins primary tubercles.

FIGURED SPECIMENS.—USNM 170476–170480, 170503.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Miocene, Dam Formation, localities S-357, S-360, S-137. Three internal molds from S-568 appear to belong to this species but are not well enough preserved to be certain.

Family TOXOPNEUSTIDAE Troschel

Genus *Schizechinus* Pomel

Schizechinus pentagonus Kier, new species

FIGURE 47; PLATES 55, 56

DIAGNOSIS.—This species is characterized by its pentagonal marginal outline, ambulacral tuberculation consisting of two rows of primary tubercles near pore series with interrarial area lacking primary tubercle approximately as wide as single pore series, and narrow, perpendicular gill slits.

MATERIAL.—Eight specimens.

SHAPE.—Diameter 22.0–42.7 mm, mean 28.1 mm (S.D. 7.8, C.V. 28.1, N-6), marginal outline pentagonal in large specimens with apices in ambulacra; circular in small specimens; height 50.1 percent of diameter (S.D. 1.2, C.V. 2.4, N-3); adoral surface depressed around peristome.

APICAL SYSTEM.—Average diameter of system as measured through genitals 1, 4, 20 percent diameter test; genital 2 larger than other genitals; ocular V,

I insert (Figure 47); periproct elongate transversely, posteriorly situated in apical system.

AMBULACRA.—Wide, with width at ambitus 22 percent of diameter of test (S.D. 7.3, C.V. 33, N-7), width at peristome 10.7 percent of diameter of test (S.D. 3.5, C.V. 32, N-7); not widening adorally, trigeminate with porepairs in arcs of three; each compound plate echinoid, with middle porepair nearest adradial suture, adoral porepair farthest away; 66 porepairs in single poriferous zone of specimen 22.2 mm in diameter, 79 in specimen 27.6 mm, 83 in specimen 30.3 mm, 101 in specimen 42.7 mm in diameter; average of 2.67 porepairs for each millimeter of diameter; porepairs in peripodia with pores arranged obliquely with outer pore of pair adapical to inner (Plate 56: figure 3); width of interporiferous zone 16.6 percent of diameter of test (S.D. 3.6, C.V. 29, N-7).

INTERAMBULACRA.—Width of interambulacrum at ambitus 29.5 percent diameter of test (S.D. 9.3, C.V. 31.6, N-7); width of interambulacrum at peristome 12.5 percent diameter of test (S.D. 3.6, C.V. 29, N-7); 16 plates in single row in specimen 22.2 mm in diameter, 19 in specimens 27.6 and 30.3 mm in diameter, 22 in specimen 42.7 mm.

FIGURE 47.—*Schizechinus pentagonus* Kier, new species: apical system of the figured paratype USNM 170475 from the Dam Formation at locality S-126, $\times 10$.

PERISTOME.—Opening circular to slightly pentagonal with apices in interambulacra; diameter 37.1 percent diameter of test (S.D. 2.6, C.V. 7.1, N=6); gill slits deep, entering almost perpendicular to edge of peristome (Plate 55: figure 6; Plate 56: figure 5).

TUBERCULATION.—Tubercles imperforate, not crenulate.

Interambulacra: On each plate at ambitus two tubercles in smaller specimens, three to four in larger specimens in horizontal row parallel to long dimension of plate (Plate 55: figure 2); along adradial suture pair of tubercles vertically arranged alternating with plate with single tubercle; plates near apical system with only single tubercle.

Ambulacra: On largest specimen near apical system one primary tubercle on each plate; midway between apical system and ambitus one larger tubercle near pore series but a second tubercle present on some plates nearer interradiat suture; at ambitus two tubercles on each plate with few small secondaries scattered between inner primaries (Plate 55: figure 4); width between double series of tubercles (midzone width) equal to width of single double series of tubercles; on smaller specimens only one larger tubercle on each plate (Plate 56: figure 3).

COMPARISON WITH OTHER SPECIES.—This species resembles most *Schizechinus duciei* (Wright) from the Miocene (Aquitainian) of Malta and Miocene (Pontian) of Algeria. I compared the Arabian specimens with a specimen of *S. duciei* kindly lent me by Dr. Rickards of the Sedgwick Museum and the specimens are similar but clearly not conspecific. *S. pentagonus* differs in having a pentagonal marginal outline, a wide zone lacking primary tubercles in the perradial area of the ambulacra (compare Plate 55: figure 4 to Plate 57: figure 1), and narrower, deeper gill slits with less of a flange developed on the inner edge of edge notch.

S. pentagonus is similar to *S. angulosus* (Pomel) from the Pliocene of Algeria in having a pentagonal test but is easily distinguished from it by its lower test with a mean height of 50.1 percent D as opposed to 65 percent in Pomel's specimen, less steep sides, and presence of only two smaller tubercles near the adradial suture on every other plate instead of four.

TYPE SPECIMENS.—Holotype, USNM 170473; figured paratypes, USNM 170474–170475.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Miocene, Dam Formation, locality S-126.

Order CLYPEASTEROIDA A. Agassiz

Suborder LAGANINA Mortensen

Family FIBULARIIDAE Gray

Genus *Fibularia* Lamarck

Fibularia damensis Kier, new species

PLATE 59: FIGURES 2–10; PLATE 60: FIGURE 1

Echinocyamus sp., Steineke, Bramkamp, Sander, 1958: 1313.—Powers, Ramirez, Redmond, and Elberg 1966: D92, D93, D95, D97

DIAGNOSIS.—Species characterized by well-developed petals and low test with height equal to 54.6 percent of the length of the test.

MATERIAL.—Hundreds of specimens but description based on 38 specimens from one locality.

SHAPE.—Test 4.5–10.0 mm long with mean of 7.1 mm, greatest width at apical system or anterior, width 86.6 percent L (S.D. 3.5, C.V. 4.1, N=37); greatest height anterior to apical system, height 54.6 percent L (S.D. 4.9, C.V. 8.9, N=38); adapical surface flat or slightly inflated, petals flush on some specimens, slightly inflated on others, apical system slightly inflated; marginal outline oblong on most smaller specimens, subpentagonal on larger with anterior pointed; periproct flush, peristome slightly depressed only along immediate edge of opening; adoral surface slightly depressed to slightly convex.

APICAL SYSTEM.—Central to slightly anterior, distance from anterior margin of test to anterior genital pores 46.7 percent L (S.D. 2.3, C.V. 4.8, N=37); width of apical system as measured across posterior genital pores 7.3 percent L (S.D. 1.3, C.V. 17.6, N=37); four genital pores arranged in trapezoid with anterior pair closer together; hydropore in furrow (Plate 59: figure 2).

AMBULACRA.—Petals long and broad, extending almost to margin, of approximately equal length; length of petal III 40.6 percent L (S.D. 2.9, C.V. 7.2, N=38), width 18.6 percent L (S.D. 1.9, C.V. 10.6, N=37); greatest width of petals near midlength or slightly distal; interporiferous zones expanding distally (Plate 59: figure 2), poriferous zones narrowing distally; pores conjugate (conjugation grooves visible only on well-preserved specimens), opening circular; smallest specimen 4.5 mm long with 8 porepairs in

single poriferous zone in petal I, 6 in petals II and III, largest specimen 9.8 mm long with 12 in petal I, eleven in petals II, III; average of 8.8. porepairs in all measured specimens in petal I, 7.1 in II, 8.5 in III with mean of 1.2 porepairs in single poriferous zone for each millimeter of length of test in petal I, 1.0 in petal II, 1.2 in petal III.

PERISTOME.—Central, subcircular to subpentagonal, slightly higher than wide (Plate 59: figure 4), height 13.5 percent L (S.D. 1.6, C.V. 12.1, N-38).

PERIPROCT.—Situated nearer peristome than posterior margin, at distance from peristome equal to 9.7 percent L (S.D. 1.6, C.V. 16.5, N-38); oblong, height greater than width, opening smaller than peristome.

INTERNAL STRUCTURES.—No internal structure (Plate 60: figure 1); auricles interradiar.

COMPARISON WITH OTHER SPECIES.—This species is easily distinguished from most species of *Fibularia* by its well-developed petals. It is most similar to *Fibularia dubarensis* Kier from the Miocene of British Somaliland in having similarly shaped petals, and my first impression was that the Arabian specimens belonged to this species. When I described the Somaliland species I did not make an adequate number of measurements and therefore could not make a definitive comparison of the Arabian and Somaliland specimens. I borrowed from the Sedgwick Museum 86 specimens and have now made the necessary measurements, the compilation of which follows this paragraph. The Arabian species is distinguished from the Somaliland *F. dubarensis* by its lower test with a height equal to 54.6 percent the length as opposed to 65.8 percent in *F. dubarensis*. A student t-test shows that the chances are far less than one in a thousand that the specimens came from one population.

The following are the statistics of 70 specimens of *Fibularia dubarensis* Kier, 1957:870, from the Miocene of British Somaliland. These specimens are in the Sedgwick Museum, Cambridge, England.

Length: mean 8.1 mm (S.D. 2.2, C.V. 28.3, N-70).
Percent width of L: 87.9 (S.D. 3.1, C.V. 3.5, N-70).
Percent height of L: 65.8 (S.D. 5.8, C.V. 8.7, N-70).
Percent length of petal III of L: 45.6 (N-60).

Percent width of petal III of L: 18.5 (S.D. 2.1, C.V. 11.7, N-63).

Percent width of apical system of L: 7.4 (S.D. 1.1, C.V. 15.4, N-66).

Percent distance from apical system to anterior margin of L: 47.5 (S.D. 3.1, C.V. 6.5, N-68).

Percent height of peristome of L: 12.8 (S.D. 1.8, C.V. 14.3, N-61).

Percent height of periproct of L: 10.5 (S.D. 1.2, C.V. 11.5, N-62).

Percent distance from periproct to peristome of L: 9.0 (S.D. 2.3, C.V. 19.6, N-63).

Ratio of number of porepairs in single poriferous zone to length of test in millimeters.

Petal I: 1.4

Petal II: 1.2

Petal III: 1.5

Fibularia damensis in general appearance resembles *Echinocyamus woodi* Currie (1930:172) from the Miocene of British East Africa. Dr. Currie does not state whether her species has internal partitions which would be expected if it was an *Echinocyamus*. *F. damensis* differs in having fewer porepairs in its petals. Her figured specimen of *E. woodi* which is 8.4 mm long has 12-13 porepairs in each poriferous zone, whereas a specimen of similar size of *F. damensis* has only 7-10.

TYPE SPECIMENS.—Holotype, USNM 170481; figured paratypes, 170482-170484.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Miocene, Dam Formation, localities S-137, S-178, S-553, S-568, S-1392.

Suborder SCUTELLINA Haeckel

Famly ASTRICLYPEIDAE Stefanini

Genus *Echinodiscus* Leske

Echinodiscus ginauensis Clegg

PLATE 66: FIGURES 4, 5

Echinodiscus ginauensis Clegg, 1933:10, pl. 1: figs. 4a,b

There is one moderately well-preserved specimen and five fragments that can be referred to this species known from Iran. Although the Arabian specimen has closed lunules, and they are open in the Persian, this character is commonly variable within a species as noted in the description herein of *Echinodiscus desori* Duncan and Sladen. In all other characters the Arabian specimens are indistinguishable from the Persian.

FIGURED SPECIMEN.—USNM 170502.

STRATIGRAPHIC OCCURRENCE AND LOCALITY IN ARABIA.—Eocene–Oligocene? (see Introduction for discussion); locality S-1603.

Echinodiscus desori Duncan and Sladen

FIGURE 48; PLATE 60: FIGURES 2–6; PLATE 61: FIGURES 1, 2

Echinodiscus desori Duncan and Sladen, 1883:60, pl. 12: figs. 7–10; 1885:328, pl. 51: figs. 1–6, 8.—Mortensen 1948:414

There is a large collection of specimens which appear to be conspecific with this species previously described from the Miocene of Kachh and Miocene Gaz deposits of western Sind. I was able to borrow three specimens of this species from the British Museum (Natural History); a photograph of one of the specimens is included (Plate 61: figure 2).

The Arabian specimens are described below:

MATERIAL.—From two localities, 60 specimens, but following description is based on 37 specimens from one locality.

SHAPE.—Test small, largest specimen 31.1 mm long, smallest 15.9, mean 22.3; width slightly less than, equal to, or slightly more than length, width 100.8 percent L (S.D. 2.1, C.V. 2.1, N-23); test low, height 16.9 percent L (S.D. 2.0, C.V. 11.9, N-25), greatest height at apical system or slightly anterior; marginal outline broadly indented at anterior ambulacra, narrowly indented at posterior, greatest width of test posterior to center; adapical surface sloping more steeply anterior of apical system than posterior, margin sharp, thin; adoral surface flat to slightly depressed.

APICAL SYSTEM.—Slightly inflated, anterior of center, mean distance from anterior of test 46.8 percent L (S.D. 1.9, C.V. 4.0, N-25); system large, mean distance between posterior genital pores 7.8 percent L (S.D. 1.3, C.V. 16.9, N-23); four genital pores (Plate 60: figure 3), anterior pair closer together than posterior.

AMBULACRA.—Ambulacra petaloid, petals slightly inflated, petal III generally longest, with mean 18 percent longer than petals II, IV, 22 percent longer than petals V, I; three of 25 specimens with petal III equal in length to petals II, IV; petal III with mean length 25.7 percent L (S.D. 2.1, C.V. 8.1, N-25); petals II, IV generally shorter than petal III, always longer than petals V, I, mean length 23.8 percent L

(S.D. 2.6, C.V. 10.8, N-25); petals V, I shortest, mean length 20.3 percent L (S.D. 2.5, C.V. 12.4, N-24); petals of approximately equal width, mean width of petal III 13.4 percent L (S.D. 1.2, C.V. 9.0, N-25), petals II, IV 13.2 percent (S.D. 1.1, C.V. 8.2, N-24), petals V, I 12.8 percent (S.D. 1.0, C.V. 7.6, N-24); span of anterior petals 51.2 percent L (S.D. 6.3, C.V. 12.5, N-21), span of posterior petals 34.2 percent L (S.D. 3.6, C.V. 10.4, N-24); single poriferous zone at its widest two thirds as wide as interporiferous zone; pores conjugate, outer pore of pair transversely elongated, slitlike; single poriferous zone of petal III with from -2 to +5 more pore-pairs than single zone in petal II (average +0.6), -1 to +5 (average +1.7) than in petal I; smallest specimen, 15.9 mm long with 19 porepairs in single poriferous zone of petal III, 17 in petal II, 18 in petal I; specimen 24.2 mm long with 26, 24, and 22 porepairs in single zone of petals III, II, and I, respectively, and largest specimen 31.1 mm long with 30, 25, 25.

Ambulacral food grooves bifurcating just outside basicoronal plates and commonly again near margin (Plate 60: figure 5); accessory pores largest in food groove, occurring in two rows in each food groove adoral to first bifurcation (Plate 60: figure 5).

PERISTOME.—Anterior, distance from center of peristome to anterior margin of test 46.0 percent L (S.D. 1.2, C.V. 2.5, N-20); opening pentagonal (Plate 60: figure 5) with apices in interambulacra, width of peristome 6.8 percent L (S.D. 1.0, C.V. 14.9, N-13); pair of buccal pores at edge of peristome at ambulacra separated from each from vertical ridge; edge of peristome in both interambulacra and ambulacra vertical.

PERIPROCT.—Inframarginal, occurring near posterior margin, distance from posterior edge of periproct to posterior margin of test 2.1 percent L (S.D. 1.5, C.V. 72.2, N-22); opening small, width 4.9 percent L (S.D. 1.0, C.V. 20.4, N-22), anterior edge of opening commonly more pointed (Plate 60: figure 6).

LUNULES.—Two lunules or notches in posterior ambulacra; shape variable, 15 of the 27 specimens in which lunules or notches preserved have both lunules closed (Figure 48A, B), seven specimens have one open (Figure 48C), the other closed, and five have both open; the lunule or notches are commonly narrow and elongate (Figure 48A) but in some speci-

FIGURE 48.—*Echinodiscus desori* Duncan and Sladen: A–C, adapical views showing the variation in the shape of the lunules; A, hypotype USNM 170509, B, hypotype USNM 170510, C, hypotype USNM 170511, $\times 2.3$, D, adoral view of hypotype USNM 170512 showing adoral plate arrangement, $\times 2.7$. All from the Dam Formation at locality S-532.

mens they are much wider (Figure 48B), width of lunule 7.6 percent L (S.D. 1.3, C.V. 16.5, N-19).

TUBERCULATION.—Tubercles uniformly small adapically; adorally larger in interambulacra, very small bordering food grooves.

ADORAL PLATE ARRANGEMENT.—Plate sutures not entirely visible on any specimen but from study of all the specimens the following can be discerned. Basi-

coronal ambulacral plates small, pair in each area, basicoronal interambulacral plate nearly twice as long, single plate in each area (Figure 48D); interambulacral areas separated from basicoronal plates by first pair of postbasicoronal ambulacral plates, 6 or 7 plates in each area on oral surface; ambulacral areas much wider than interambulacra with from 6–8 plates in each postbasicoronal area.

REMARKS.—Most of the species of this genus and *Amphiope* have been described on very few specimens and considerable emphasis has been placed on the shape of the lunules. The lunules in this Arabian species, however, are very variable. In some specimens they are long and narrow, in others wide, and in some the lunules are notches opening posteriorly. They are probably just as variable in many of the other species. Much more diagnostic features are the length and width of the petals relative to each other and to the length of the test, the position and size of the periproct and peristome, width and height of the test relative to the length of the test, distance between the genital pores, and number of porepairs in the petals. Very little variation in these features is present in the specimens of this species. Unfortunately, these dimensions are given for very few of the known species, making comparison difficult.

This species could also be referred to *Amphiope* and appears to be intermediate between the two genera. Most workers have distinguished the genera on the basis of the shape of the lunules—elongate transversely in *Amphiope* but elongate longitudinally in *Echinodiscus*. In this species, however, the lunules are elongate longitudinally in most of the specimens but circular to slightly elongate transversely in a few.

FIGURED SPECIMENS.—USNM 170485–170486, 170509–170512.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Miocene, Dam Formation. S-532, statistics taken from specimens from this locality; locality S-126.

Family LAGANIDAE A. Agassiz

Genus *Laganum* Link

Laganum tumidum Duncan and Sladen

FIGURES 49; PLATE 61: FIGURES 3–9; PLATE 62: FIGURE 1

Laganum tumidum Duncan and Sladen, 1886:379, pl. 58: figs. 6–10.—Pilgrim 1908:41.—Brighton 1931:325–326.—Mortensen 1948:321

There are 75 specimens from Arabia which can be referred to this species previously reported from the Pliocene Makran Series of Kharak Island in the Persian Gulf and the Miocene Fars Series of Iran. I have compared them to a large collection of *Laganum tumidum* very kindly lent me by Richard Jef-

feries of British Museum (Natural History), and they are identical.

Brighton proposed that *L. tumidum* was the same as *L. depressum* L. Agassiz now living in the Gulf of Suez, Persian Gulf, Indian Ocean, and western Pacific. Mortensen considered it to be just a variety of this living species. On general impression the two species appear to be very similar, but statistical analysis of their measurements show that they are distinct. Miss Ailsa Clark of the British Museum (Natural History) lent me 29 specimens of *L. depressum*. The statistics of these specimens are included below. *L. tumidum* differs from *L. depressum* in having a wider test, longer narrower petals, its posterior genital pores closer together and its periproct farther away from the posterior margin. As can be seen on the table of values in the student t-test, in all these characters except the width of the posterior genital pores the difference between each species is very distinct with a chance of less than one in a thousand of the two populations being one.

MATERIAL.—A total of 75 specimens, with statistics taken from 25 specimens.

SHAPE.—Length from 9.8 to 44.4 mm, mean 31.1 (S.D. 10.9, C.V. 35.3, N=25); width 89.5 percent L (S.D. 2.7, C.V. 3.0, N=23) (Figure 49A); marginal outline smoothly rounded in small specimens, pentagonal in large specimens (Plate 62: figure 1) with greatest width anterior, blunt posterior margin; margin thick; greatest height at apical system, height 19.6 percent L (S.D. 2.0, C.V. 10.2, N=14); adapical surface flat or depressed near end of petals; adoral surface depressed.

APICAL SYSTEM.—Central, distance anterior margin to apical system 46.7 percent (S.D. 2.6, C.V. 5.5, N=21) madreporite pores concentrated in curving line, five genital pores, no genital pores in specimens less than 15 mm long; width of apical system 5.9 percent L (S.D. 1.0, C.V. 16.6, N=15).

AMBULACRA.—Petals extending between one half to two thirds distance from apical system to margin; length of petal III 26.5 percent L (S.D. 2.0, C.V. 7.6, N=21), petal II 24.1 percent (S.D. 2.1, C.V. 8.8, N=21), petal I 26.7 percent (S.D. 1.9, C.V. 7.2, N=21); petals slightly closing with both poriferous and interporiferous zones narrowing distally; span of anterior petals as measured from outside edge of petals 55.6 percent L (S.D. 5.2, C.V. 9.5, N=21), span posterior petals 39.1 percent (S.D. 6.5, C.V. 16.7,

FIGURE 49.—*Laganum tumidum* Duncan and Sladen: scattergrams of the length of the test relative to the width of the test (A), and of the number of porepairs in a single poriferous zone in petal II relative to the length of the test (B).

N-20); width of petal III 9.4 percent (S.D. 1.1, C.V. 11.2, N-21), width petal II 9.7 percent L (S.D. 1.1, C.V. 11.8, N-21); width petal I 9.9 percent L (S.D. 1.0, C.V. 10.4, N-21); smallest specimen 9.8 mm long with 17 porepairs in single poriferous zone of petal III, 15 in II, 18 in I; largest specimen 44.4 mm long with 43 in III, 39 in II, 42 in I; mean of 1.0 porepairs in single poriferous zone for each millimeter of length of test in

petal III (Figure 49B); 1.3 in petal II, 1.0 in petal I; accessory pores present in interporiferous zones, in great numbers adorally over entire ambulacra.

PERISTOME.—Slightly anterior, distance from center of peristome to anterior margin 49 percent L (S.D. 2.2, C.V. 4.5, N-17); circular to pentagonal with apices in interambulacra, width equal length, 7.9 percent L (S.D. 1.6, C.V. 10.5, N-18); buccal pores at margin.

PERIPROCT.—Located at distance from peristome equal to 13.1 percent L (S.D. 2.0, C.V. 15.9, N-19); opening elongated transversely with height (measured longitudinally) 80-90 percent of width; opening small, width 6.7 percent L (S.D. 0.7, C.V. 10.5, N-18); located between fourth to fifth plate.

ADORAL PLATE ARRANGEMENT.—Interambulacra narrow, continuous, terminated by single plate; primordial ambulacral plates larger than primordial interambulacral plates; basicoronal plates pentagonal with apices extending into ambulacra.

FIGURED SPECIMENS.—USNM 170487-170491.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Miocene, Dam Formation, locality S-1914.

Comparison of *Laganum tumidum* and *L. depressum*

	Mean percent of length of test	Significance of difference
	<i>L. tumi- dum</i>	<i>L. depres- sum</i> of t-test (two sided)
Width of test	89.5	81.1 .001
Length petal III	26.6	31.8 .001
petal II	24.1	27.0 .001
petal I	26.7	23.0 .001
Width petal III	9.4	11.2 .001
petal II	9.7	11.8 .001
petal I	9.9	11.7 .001
Width posterior genital pores	5.9	7.0 .01
Distance periproct to posterior margin	13.1	11.1 .001

Statistics of 29 specimens of the Recent
Laganum depressum

	Mean	S.D.	C.V.	N
Length (L)	37.6	6.9	17.8	29
Percent width of L	81.1	3.4	4.2	29
Percent height of L	19.7	2.2	11.4	29
Percent distance from center of apical system to anterior margin of L	46.8	3.6	7.8	29
Percent L of length of Petal III	31.8	2.3	7.2	29

Statistics of 29 specimens of the Recent
Laganum depressum—Continued

	Mean	S.D.	C.V.	N
Petal II	27.0	2.1	7.6	29
Petal I	23.0	2.2	6.8	29
Percent L span of anterior petals	57.2	3.8	6.7	29
Percent L span of posterior petals	40.5	4.8	11.8	29
Percent L of width of				
Petal III	11.2	1.1	9.4	29
Petal II	11.8	1.0	8.5	29
Petal I	11.7	1.1	9.4	29
Percent L of width between posterior genital pores	7.0	1.2	17.3	25
Percent L of width of peristome	7.9	0.9	12.1	24
Percent L of width of periproct	7.3	0.9	13.4	28
Percent L of distance from periproct to the posterior margin	11.1	1.4	12.8	27
Percent L of distance from center of peristome to the anterior margin	47.8	0.9	1.9	26
Number of porepairs in single poriferous zone of				
Petal III	40.8	6.2	15.2	26
Petal II	35.4	5.7	16.0	27
Petal I	42.6	6.2	14.5	29

Order SPATANGOIDA Claus

Suborder HEMIASTERINA Fischer

Family SCHIZASTERIDAE Lambert

Genus *Agassizia* Agassiz and Desor

Agassizia (Anisaster) arabica Kier, new species

PLATE 65: FIGURES 3–8; PLATE 66: FIGURES 1–3

DIAGNOSIS.—Species characterized by its anterior apical system and by having the porepairs in the anterior poriferous zones of the anterior petals enlarged almost to the size of the porepairs of the posterior zones.

MATERIAL.—Number of specimens, 30, but description based on 23 from same locality.

SHAPE.—Specimens 10.6–22.0 mm long, mean 17.2 mm (S.D. 3.2, C.V. 18.8, N=16); width 96.2 percent L (S.D. 2.4, C.V. 2.5, N=14); height 84.5 percent L (S.D. 24.5, C.V. 28.9, N=15); greatest width central,

anterior margin smoothly rounded, posterior truncated vertically to slightly overhanging; greatest height anterior to apical system; an anterior groove at ambitus.

APICAL SYSTEM.—Slightly posterior to center, located at distance from anterior margin to center of system equal to 53.5 percent L (S.D. 3.5, C.V. 6.6, N=14); ethmolytic, four genital pores arranged in trapezoid with anterior pair closer together.

AMBULACRA.—Anterior ambulacrum (III) not petaloid, slightly depressed in faint groove until near margin where flush with test; porepairs minute.

Anterior paired petals (II, IV) curving backward from near midlength of petal, extending approximately two thirds distance to margin; anterior poriferous zones composed of minute porepairs except near ends of petals where porepairs enlarge (Plate 66: figure 1); length of petal equal to 42.4 percent L (S.D. 5.2, C.V. 12.2, N=12); maximum width 8.1 percent L (S.D. 0.9, C.V. 11.6, N=13); depth of petal 1.2 percent L (S.D. 0.4, C.V. 35.6, N=14); number of porepairs in posterior poriferous zone varying from 13 in small specimen 10.8 mm long to 20 in specimen 19.7 mm long with an average of 1 porepair for every millimeter of length; span of anterior petals 6.6 percent L (S.D. 5.7, C.V. 8.5, N=12).

Posterior paired petals (V, I) 65 percent as long as anterior with length of petal equal to 27.8 percent L (S.D. 2.1, C.V. 7.8, N=14); width 10.9 percent L (S.D. 0.5, C.V. 4.9, N=13); depth of petal 2.2 percent L (S.D. 0.8, C.V. 39.3, N=13); span of petals 39.7 percent L (S.D. 2.0, C.V. 4.9, N=14); petals straight or curving very slightly anteriorly; interporiferous zones narrower than single poriferous zone, anterior zone not reduced; number of porepairs in single poriferous zone varying from 11 in smallest specimen 10.6 mm long to 16 in specimen 22 mm long with an average of 1.2 porepairs for every millimeter of length of test.

PERISTOME.—Anterior, mean distance from anterior edge of peristome to anterior margin of test 21.7 percent L (S.D. 2.3, C.V. 10.9, N=15); wider than high.

PERIPROCT.—Located high on posterior truncation, wider than high, width equal to 19.9 percent L (S.D. 2.3, C.V. 10.9, N=15).

ADORAL PLATE ARRANGEMENT.—Labrum wide and low, height 5.4 percent L (S.D. 0.9, C.V. 18.1, N=5); plastron mesamphisternous (as defined by Fischer 1966:548 in the Treatise) with length equal 58.7 percent L (S.D. 10.6, C.V. 18.1, N=9), width of plastron

46.9 percent L (S.D. 7.1, C.V. 15.2, N=11); interambulacra 4, 1 amphiplacous with first plate abutting against two plates; plastron slightly inflated.

FASCIOLAS.—Peripetalous fasciole passing directly across (curving slightly toward apical system) from ends of posterior petals, curving deeply inward toward apical system between posterior and anterior petals, dropping down below ambitus anterior of anterior petals. Lateroanal fasciole extending from peripetalous fasciole near ends of anterior petals, passing in deep trough below periproct.

COMPARISON WITH OTHER SPECIES.—This species resembles most *Agassizia powersi* Kier, new species, from the Burdigalian of Saudi Arabia. It differs in having the porepairs in the anterior poriferous zones of the anterior petals not all minute as in *A. powersi*, but in having the porepairs near the end of the petals enlarged almost to normal size. Furthermore, the anterior petals in *A. powersi* do not extend as far down the test as viewed from the side. *A. arabica* has a wider test with a width equal to 96.2 percent L as opposed to 91.9 in *A. powersi*, and a higher test, 84.5 percent L as opposed to 79.5 percent. Its anterior petals are shorter, 42.4 percent L versus 55.7 in *A. powersi*. The span of its anterior petals is less, only 66.6 percent L, whereas it is 73.1 percent L in *A. powersi*.

TYPE SPECIMENS.—Holotype, USNM 170501; figured paratype, USNM 170500.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Eocene–Oligocene? (see Introduction for discussion); localities S-761, S-1603.

Agassizia (Agassizia) powersi Kier, new species

PLATE 64; PLATE 65: FIGURES 1, 2

DIAGNOSIS.—Species characterized by its anterior apical system and high test with the height equal to 79.5 percent of the length.

MATERIAL.—A total of 139 specimens, description and statistics taken from 32 specimens from same locality.

SHAPE.—Specimens 7.1–20.2 mm long, mean 15.4 mm (S.D. 3.3, C.V. 21.7, N=32); width 91.8 percent L (S.D. 2.2, C.V. 2.4, N=30); height 79.5 percent L (S.D. 3.5, C.V. 4.4, N=32); test slightly angular in marginal outline with greatest width central, greatest height slightly anterior of apical system; posterior truncation vertical in most specimens, slightly over-

hanging in few; no anterior groove at ambitus.

APICAL SYSTEM.—Central, located at distance from anterior margin to center of system equal to 52.7 percent L (S.D. 3.5, C.V. 6.6, N=32); ethmolytic, 4 genital pores in thirty specimens, 5 in two; pores arranged in trapezoid with anterior pair closer together.

AMBULACRA.—Anterior ambulacrum (III) not petaloid, slightly depressed in faint groove until near margin where flush with test; porepairs minute.

Anterior paired petals (II, IV) curving backward slightly, extending almost to margin; anterior poriferous zone composed of minute porepairs extending throughout entire length of petal; petals narrow with maximum width 7.7 percent L (S.D. 0.6, C.V. 7.6, N=32); length of petal equal to 55.7 percent L (S.D. 4.9, C.V. 8.7, N=32); depth of petal 8 percent L (S.D. 0.3, C.V. 35.1, N=31); span of anterior petals 73.1 percent L (S.D. 3.5, C.V. 4.7, N=27); number of porepairs in posterior poriferous zone varying from 14 in smallest specimen 7.1 mm long to 23 in specimen 18.5 mm long with an average of 1.3 porepairs for every millimeter of length of test.

Posterior paired petals (V, I) 32 percent as long as anterior with length of petal equal to 26.0 percent L (S.D. 2.9, C.V. 11.0, N=32); width 10.2 percent L (S.D. 0.8, C.V. 7.9, N=32); depth of petal 1.2 percent L (S.D. 0.5, C.V. 40.6, N=32); span of petals 35.8 percent L (S.D. 3.3, C.V. 9.3, N=30); petals straight; interporiferous zones narrower than single poriferous zone, anterior poriferous zone not reduced; number of porepairs in single poriferous zone varying from 12 in smallest specimen 7.1 mm long to 32 in specimen 18.5 mm with an average of 1.4 porepairs for every millimeter of length of test.

PERISTOME.—Anterior, mean distance from anterior edge of peristome to anterior margin of test 20.7 percent L (S.D. 3.1, C.V. 14.9, N=31); anterior of opening slightly depressed into test.

PERIPROCT.—Located high on posterior truncation, wider than high, width equal to 19.6 percent L (S.D. 1.9, C.V. 9.8, N=15); height 15.3 percent L (S.D. 2.3, C.V. 15.2, N=14); enclosed by plates 5–7 of interambulacrum 5.

ADORAL PLATE ARRANGEMENT.—Labrum, wide and low, height 5.2 percent L (S.D. 0.9, C.V. 17.1, N=15); plastron mesampisternous (as defined by Fischer 1966:548 in the Treatise) with length equal 54.7 percent L (S.D. 3.4, C.V. 6.2, N=23), width

of plastron 44.7 percent L (S.D. 2.5, C.V. 5.7, N=28); interambulacra 4, 1 amphiplacous with first plate abutting against two plates; plastron slightly inflated.

FASCIOLAS.—Peripetalous fasciole passing directly across from ends of posterior petals, curving inward toward apical system between posterior and anterior petals dropping down below ambitus anterior of anterior petals. Lateroanal fasciole extending from peripetalous fasciole near ends of anterior petals, passing in deep trough below periproct.

COMPARISON WITH OTHER SPECIES.—This Arabian species may be conspecific with the specimens Clegg (1933:29, pl. 3: figs. 6a,b,c,d) referred to *Agassizia scrobiculata* Valenciennes var. *persica* Clegg from the Fars Series of Persia. The Persian specimens, however, are not well enough illustrated or enough dimensions available to be certain whether they are conspecific. It is very similar to *A. scrobiculata* Valenciennes now living from the Gulf of California to Peru and the Galapagos and known as a fossil from the lower Pliocene of the Gulf of California (Durham 1950:50, pl. 43: figs. 4–5, 8–9). Its dimensions are very similar, but it differs in having a higher test with a height 79.5 percent of its length as opposed to 71.3 in *A. scrobiculata*. Unfortunately, I have only two specimens of the Recent species and I cannot statistically test this difference, but the little variability shown in this character in other species of *Agassizia* is evidence that this difference is significant.

A. powersi is easily distinguished from most of the fossil species by its more anterior apical system such as *A. floridana* de Loriol, *A. inflata* Jackson, *A. caribbeana* Weisboard, *A. cyrenaica* Desio, *A. clevei* Cotteau, *A. castexi* Lambert, *A. flexuosa* Sanchez Roig, *A. avilensis* Sanchez-Roig, *A. guanensis* Sanchez-Roig.

TYPE SPECIMENS.—Holotype, USNM 170497; figured paratypes, USNM 170498–170499.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Miocene, Dam Formation, localities S-357, S-360, S-361, S-568.

Genus *Moira* A. Agassiz

Moira adamthi Clegg

Moira adamthi Clegg, 1933:27, pl. 3: figs. 4, 5

There are 13 specimens, most of which are extremely well preserved, of this species previously known from the Miocene (Burdigalian), Lower Fars Formation from South Persia. These specimens are similar in every way to the Persian specimens (I have compared them to a cast of the holotype) and there is little doubt that they are conspecific. Clegg only had two specimens when he described his species and therefore gave little biometric data. A detailed description of the Arabian specimens is included below.

SHAPE.—Specimens 22.6–29.8 mm long, mean 24.6 mm (S.D. 2.7, C.V. 10.9, N=9); width 89–95 percent L, mean 92.8 percent (S.D. 1.9, C.V. 2.0, N=9); height 61–75 percent L, mean height 69.7 percent (S.D. 4.1, C.V. 5.8, N=8); test slightly angular in marginal outline with greatest width anterior, sides tapering posteriorly, anterior margin blunted; posterior truncation varying from slightly overhanging, to vertical, to tilted toward apical system but not enough to make periproct visible from above; petals and anterior groove deeply depressed with entrance to them very narrow with interambulacra almost meeting above them especially adapically in anterior paired petals; depth of anterior petals 13.2 percent L (S.D. 1.0, C.V. 7.4, N=8), depth of posterior petals 10.6 percent L (S.D. 1.5, C.V. 13.8, N=8), depth of anterior groove 5.4 percent L (S.D. 0.7, C.V. 12.9, N=9); adoral surface flattened except for inflated plastron.

APICAL SYSTEM.—Central, located at distance from anterior margin to pore of ocular III equal to 43–54 percent L, mean 47.1 percent (S.D. 4.1, C.V. 8.8, N=9); two genital plates, two genital pores, both genital plates narrow, curving anteriorly with ocular plates inserted deeply into genital plates.

AMBULACRA.—Anterior ambulacrum (III) deeply sunken with poriferous zones located on floor of groove; pores of pair much closer together and smaller than in paired petals; groove reaches greatest depth two thirds to four fifths distance from apical system to end of petal, passing over margin as shallow groove continuing to near peristome (for a detailed description of the morphology and function of this anterior petal in a very similar species see Chesher 1963).

Anterior paired petals (II, IV) deeply depressed, curving sharply backward at approximately 40 percent distance from apical system to end of petal;

petals narrow with maximum width 4.2 percent L (S.D. 1.0, C.V. 24.8, N-9); length of petal as measured from ocular pore in straight line to end of groove equal to 44.1 percent L (S.D. 1.7, C.V. 3.8, N-9); pores very large, widely separated from each other with outer pore of pair high in groove, facing downward, inner pore of pair on floor of groove; span of petals as measured across test from ends of petals 68.1 percent L (S.D. 1.7, C.V. 2.5, N-9).

Posterior paired petals (V, I) 61 percent as long as anterior with length as measured from ocular pore to end of groove 27.1 percent L (S.D. 1.9, C.V. 6.9, N-9); petals curving posteriorly; porepairs as in anterior paired petals; span of petals as measured across test from ends of petals 34.1 percent L (S.D. 2.1, C.V. 6.0, N-9); petals narrow with maximum width 3.2 percent L, mean percent (S.D. 1.1, C.V. 34.8, N-9).

Ambulacra beyond petals with single pore in each plate; phyllodes with 3 pores in ambulacrum III, 5-6 in II, 6 in I.

INTERAMBULACRA.—Single node present on most adapical plates forming series running toward margin; 21 plates in interambulacrum 5 of all seven specimens in which count could be made, 12-13 in interambulacrum 1 (two specimens with 13, six with 12), 11 in seven specimens in interambulacrum 2.

PERISTOME.—Anterior, mean distance from anterior edge of peristome to posterior margin of test 72.2 percent L (S.D. 5.0, C.V. 6.9, N-8); opening slightly depressed into adoral surface; width of opening 21.1 percent L (S.D. 2.1, C.V. 9.8, N-8); greatest height of opening 7.6 percent L (S.D. 1.3, C.V. 16.9, N-7).

PERIPROCT.—Located high on posterior truncation, higher than wide, height 15.4 percent L (S.D. 1.5, C.V. 9.7, N-7); width 12.7 percent L (S.D. 1.2, C.V. 9.5, N-7); enclosed by plates 4-8 of interambulacrum column 5a, plates 3-7 of column 5b.

ADORAL PLATE ARRANGEMENT.—Labrum (Figure 50) expanded at edge of peristome, narrowing and then expanding posteriorly and extending back to posterior of first adjacent ambulacral plate; anterior border of labrum forming lip; length of labrum 10.7 percent L (S.D. 0.8, C.V. 7.1, N-5). Plastron mesamphisternous (as defined by Fischer 1966:548 in the Treatise) with length equal to 52.6 percent L (S.D. 2.5, C.V. 4.8, N-7), width of plastron 36.2 percent L (S.D. 1.9, C.V. 5.1, N-8); interambulacra 4, 1 am-

FIGURE 50.—*Moira adamthi* Clegg: adoral plate arrangement of hypotype USNM 170496 from the Miocene Dam Formation at locality S-126, $\times 4$.

phiplacous with first plate abutting against two plates; plastron only slightly inflated.

FASCIOLES.—Peripetalous fasciole bordering most of length of petals, particularly posterior petals where in contact with almost entire length of petals (Plate 63: figure 9); fasciole widest around outer two thirds of anterior paired petals, narrowest where crossing interambulacra between anterior and posterior petals; length equal to 357 percent L (S.D. 14.5, C.V. 4.0, N-7); fasciole crossing ambulacrum III on plates 4-5a, 3-4b; ambulacrum II on plates 7-8a, 8-9b, ambulacrum I on plates 3-4a, 3-4b; interambulacrum 2 on plates 4a, 3b; interambulacrum 1 on plates 6a, 4b and interambulacrum 5 on 11a, 10b; fasciole crossing ambulacrum III at distance from ocular III to fasciole equal to 44.4 percent L (S.D. 2.1, C.V. 4.8, N-8).

Lateroanal fasciole extending from anterior paired petals (from near two thirds distance from apical system to end of petaloid groove) posteriorly and adorally below periproct; length of fasciole 205 percent L (S.D. 9.0, C.V. 4.4, N-6); fasciole narrow.

COMPARISON WITH OTHER SPECIES.—In general appearance this species resembles more closely the living species of *Moira* than the Miocene and Oligocene species. It is easily distinguished from *Moira antiqua* Duncan and Sladen (1883:64, pl. 8: figs. 1–6) from the Miocene of Kachh by its far more anterior apical system, shorter anterior petals, longer posterior petals and narrower test. It differs from *M. primaeva* Duncan and Sladen (1884:225, pl. 35: figs. 1–3) from the Nari Series of western Sind in having its apical system far more anterior and in its more steeply sloping adapical anterior surface. *M. guebhardi* Lambert (1906:53, fig. 1) from the Miocene of Vence is based on one poorly preserved specimen with too few characters displayed for specific comparison. It differs from *M. obesa* Nisiyama (1935: 164, pl. 8: figs. 6–16) from the Miocene of Formosa and Japan in having a more anteriorly situated apical system and a less inflated test. It differs from the late Pliocene specimen Durham (1950:51, pl. 45: figs. 2, 5) referred to *Moira* cf. *clotho* (Michelin) in having a much lower test. This species is easily distinguished from *M. koeneni* Ebert (1889:52, pl. 5: fig. 7) from the Oligocene.

This species most resembles the living species *M. stygia* Lütken from Zanzibar and the Gulf of Suez and *M. atropos* (Lamarck) from the West Indies. It differs from *M. stygia* in having a lower test with its height averaging 69.7 percent of its length as compared to 80 percent in *M. stygia* according to A. Agassiz's (1873:616) dimensions. Furthermore, the anterior petals in the Arabian species are much more curved.

It appeared to be quite similar to *Moira atropos* (Lamarck), but a statistical analysis shows that the two species are quite distinct. No statistics in any detail of *M. atropos* have ever been published; therefore I include here the measurements from nine specimens of *M. atropos* from Tampa Bay.

Student t- and F-tests were run on the two species and the following characters were found to be significantly different:

MEAN PERCENT OF LENGTH OF TEST

	<i>M. adamthi</i>	<i>M. atropos</i>	Significance of difference by t-test (two sided)
Width of test	92.7	87.5	.001
Height of test	69.7	74.4	.02
Distance apical to anterior	47.1	52.8	.01
Width of periproct	12.7	11.1	.01
Length of posterior petals	27.1	24.5	.01
Span anterior petals	68.1	62.6	.001
Span posterior petals	34.1	30.9	.01
Length plastron	52.6	61.1	.001
Length labrum	10.7	8.5	.001
Distance apical to peripetalous fasciole	44.3	49.6	.001
Depth amb III	22.6	28.8	.001
Depth amb II	13.2	14.3	.01
Depth amb I	10.6	12.2	.05
Width plastron	36.2	42.5	.001
Distance labrum to anterior edge of peristome	3.1	1.1	.001

Moira adamthi differs from *M. atropos* in having a wider and lower test, its apical system more anterior, its periproct wider, posterior petals longer, greater span to both anterior and posterior petals, a shorter plastron, longer labrum, its peripetalous fasciole crossing anteriorly nearer the apical system, its ambulacra less depressed, its plastron narrower, and its labrum extending less anteriorly across the peristome.

M. adamthi differs from *M. lachesinella* Mortensen, living off Japan, and *M. lethe* Mortensen, from the coast of Queensland, in having a much longer labrum, lacking a projecting lower posterior margin, having more curved anterior petals, and in having a lower test (height 69.7 percent of length as compared to 75 percent in these two living species). It differs from *M. clotho* (Michelin) from the west coast of America in having a more anterior apical system and its greatest width more anterior.

FIGURED SPECIMENS.—USNM 170495–170496.

STRATIGRAPHIC OCCURRENCE AND LOCALITY IN ARABIA.—Miocene, Dam Formation, locality S-126.

STATISTICS OF *Moira atropos* (LAMARCK) FROM TAMPA BAY

	Mean	S.D.	C.V.	N
Length	26.1	2.4	9.1	9
Percent width of L	87.5	2.9	3.3	9
Percent height of L	74.4	2.5	3.3	9

STATISTICS OF *Moira atropos* (LAMARCK) FROM TAMPA BAY—Continued

	Mean	S.D.	C.V.	N
Percent distance from center of apical system to anterior margin of L	52.8	3.5	6.6	9
Percent distance from anterior edge of peristome to posterior margin of L	74.4	1.6	2.2	9
Percent of L of height of periproct	16.2	1.0	6.3	9
Percent of L of width of periproct	11.1	0.7	5.9	9
Percent of L of length of petal II	44.7	1.8	4.0	9
Percent of L of length of petal I	24.5	1.2	4.9	9
Percent of L of span of anterior petals	62.6	3.1	4.9	9
Percent of L of span of posterior petals	30.9	1.3	4.3	9
Percent of L of width of petal II	4.5	0.9	20.0	9
Percent of L of width of petal I	3.2	0.6	18.9	9
Percent of L of length of plastron	61.1	2.5	4.8	9
Percent of L of length of labrum	8.5	6.1	7.1	9
Percent of L of distance from apical system to peripetalous fasciole	49.6	3.0	6.0	9
Percent of L of depth of anterior notch	5.3	0.6	10.9	9
Percent of L of depth of petal III	28.8	2.6	9.1	9
Percent of L of depth of petal II	14.3	0.9	6.4	9
Percent of L of depth of petal I	12.2	1.3	10.6	9
Percent of L of length of peripetalous fasciole	366.6	18.7	5.1	9
Percent of L of length of lateroanal fasciole	204.6	7.7	3.7	9
Percent of L of width of peristome	19.22	0.8	4.1	9
Percent of L of height of peristome	6.0	0.6	9.7	9
Percent of L of width of plastron	42.5	1.9	4.4	9
Percent of L of distance from anterior edge of labrum to anterior edge of peristome	1.1	0.8	70.77	9

Suborder MICRASTERINA Fischer

Family BRISSIDAE Gray

Genus *Eupatagus* L. Agassiz*Eupatagus* species

PLATE 67: FIGURES 1-8

There are eleven fragments which belong to a species clearly distinct from any other species of this genus. However, because the specimens are poorly preserved, mostly only fragments, a new species is not described. This description must await the finding of better material.

FIGURED SPECIMENS.—USNM 170514-170515.

STRATIGRAPHIC OCCURRENCE AND LOCALITIES.—Eocene to Oligocene? (see introduction for discussion); locality S-761.

Genus *Brissus* Gray*Brissus latidunensis* Clegg

PLATE 62: FIGURES 5-7; PLATE 63: FIGURES 1-4

Brissus latidunensis Clegg, 1933:30, pl. 3: figs. 7a,b,c

Two nearly complete specimens and seven fragments can be referred without doubt to this species described from the Miocene (Burdigalian), Lower Fars Formation from southern Persia. I can see no difference between this species and *Brissus agassizii* Doberlein living now off Japan. More specimens are required of the Miocene species, however, before it can be decided whether the two species are synonymous.

I compared the Arabian specimens with an excellent cast of the holotype of *Brissus latidunensis* provided by the Geological Survey of India. The Arabian specimens are certainly conspecific with the type.

Roman (1970:41) considered *Brissus latidunensis* as a subspecies of *B. unicolor* (Leske). The two species, however, appear to me to be quite distinct. The posterior petals in the Arabian species are longer than in *B. unicolor* and have more porepairs. In Clegg's two specimens the posterior petals are 42 percent of the length of the test and in the two Arabian specimens they are 42 and 43 percent, whereas in *B. unicolor* they average 34.5 percent in the six specimens of

comparable size from which I could get dimensions. The Arabian specimens had 29 porepairs in a single poriferous zone of a specimen 31.2 mm long, 34 in a specimen 53.0 mm long, whereas in *B. unicolor* a specimen 36.2 mm long had only 25, and a specimen 42.3 had only 23. The ratio of porepairs in a single poriferous zone to each millimeter of length in *B. latidunensis* is 7.5, whereas it is 6.1 in comparable size specimens of *B. unicolor*. Furthermore, *B. latidunensis* is more inflated posteriorly and has narrower adoral ambulacra V and I. The width of these ambulacra midway between the peristome and the margin are 6.5 percent of the length of the test in *B. latidunensis*, whereas they are only 5.5 percent in *B. unicolor*.

The specimens that Roman figures from the late Miocene of Spain appear to be intermediate between *B. unicolor* and *B. latidunensis*.

FIGURED SPECIMENS.—USNM 170493–170494.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Miocene, Dam Formation; locality S-126.

Family LOVENIIDAE Lambert

Genus *Lovenia* Desor

Lovenia cf. *Lovenia elongata* (Gray)

PLATE 62: FIGURES 2–4

For a complete synonymy see Mortensen, 1951:97

One specimen is indistinguishable from this species which is now living in the Persian Gulf off Saudi Arabia and over the Indo-West Pacific region. Clegg found this species in the Miocene Fars Formation of Persia and considered it a variety of *Lovenia elongata*. Nowhere in his description does he state how his material differs from the living species, and I agree with Mortensen (1951:104) in being unable to see any differences. However, although the Arabian and Persian specimens appear to be indistinguishable from the living species, they may not be conspecific. Only two specimens are known from Persia and one from Arabia, an insufficient number of specimens to permit a confident determination that these specimens are conspecific with the living species.

Gregory (1906:255) reports this species from the Pleistocene of the Red Sea.

FIGURED SPECIMEN.—USNM 170492.

STRATIGRAPHIC OCCURRENCE AND LOCALITY.—Miocene, Dam Formation; locality S-126.

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PLATES

PLATE 1

Farquharsonia crenulata Kier, new species:

- 1,2,3. Adapical, adoral, side view of holotype USNM 170370 from the Middle Jurassic, middle Dhruma Formation at locality KK9-43, $\times 3$.
4. Ambulacrum III at ambitus showing plate arrangement consisting of pairs of primary plates with tubercle covering each pair separated by single primary plate with much smaller secondary tubercle; holotype, $\times 8$. A drawing of this area is on Figure 7c.
5. Ambulacrum III adapically of holotype, $\times 8$. A drawing of this area is on Figure 7b.
6. Apical system of holotype, $\times 8$. A drawing of this area is on Figure 7a.

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PLATE 2

Farquharsonia crenulata Kier, new species:

1. Edge of peristome of holotype USNM 170370 from the Middle Jurassic, middle Dhurma Formation at locality KK9-43, $\times 8$.
2. Primary tubercle of interambulacrum at ambitus of holotype showing well-developed crenulations, $\times 8$.

Farquharsonia somaliensis Currie:

- 3,4,5. Adapical, adoral, side view of hypotype USNM 170371 from the Upper Jurassic, upper Dhurma Formation at locality KK9-108, $\times 3$.
6. View of interambulacrum 2 of the same specimen showing the small primary tubercles, $\times 8$.

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PLATE 3

Farquharsonia somaliensis Currie:

1. View of interambulacrum 2 at ambitus of hypotype USNM 170371 from the Upper Jurassic, upper Dhurma Formation at locality KK9-108 showing lack of crenulations, $\times 8$.
2. Adapical portion of ambulacrum I and adjacent interambulacra of hypotype USNM 170372 from the upper Dhurma Formation at locality KK9-112 showing crenulate tubercles, $\times 10$.
- 3,4,5. Adapical, adoral, side views of same specimen, $\times 4$.
6. Ambulacrum I of same specimen showing plate arrangement consisting of pairs of primary plates with tubercle covering each pair separated by single primary plate with much smaller secondary tubercle, $\times 10$.
7. Edge of peristome of same specimen showing strongly bilobed gill slits. It is this feature that distinguishes this species from *Farquharsonia crenulata* Kier, new species, from the Middle Jurassic, middle Dhurma Formation (see Plate 2: figure 1 for comparison).

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PLATE 4

Farquharsonia somaliensis Currie:

- 1-3. Adapical, adoral, side views of a specimen identified by Currie from the Callovian Bihen Limestone of British Somaliland in the Sedgwick Museum (F-77), $\times 3$.
4. Ambulacrum at peristome of hypotype USNM 170372 from the Upper Jurassic, upper Dhurma Formation at locality KK9-112, $\times 10$.
5. Interambulacrum 4 at ambitus of hypotype USNM 170373 from the upper Dhurma Formation at locality KK9-112 showing confluent scrobicular rings, distinct basal terraces, and crenulate tubercles, $\times 8$. Commonly the tubercles are not crenulate on larger specimens (see Plate 3: figure 1 for comparison).
- 6,7. Adapical, and side view of the holotype (British Museum, Natural History, E18006) from the Callovian Bihen Limestone of British Somaliland, $\times 3$. Adoral view of this specimen on Plate 5: figure 1.

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PLATE 5

Farquharsonia somaliensis Currie:

1. Adoral view of holotype (British Museum, Natural History, E18006) from the Callovian Bihen Limestone of British Somaliland, $\times$ 3. Adapical and side views on Plate 4: figures 6, 7.

Heterosalenia ornata Kier, new species:

- 2,3,4. Adoral, side, adapical views of holotype USNM 170375 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times$ 4.
- 5,6. Adapical and side views of same specimen showing the tuberculation, $\times$ 6.

PLATE 6

Heterosalenia ornata Kier, new species:

1. Apical system of figured paratype USNM 170376 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112 showing the large knobs on the genital and suranal plates and the ridges joining these knobs, $\times 8$.
- 2,3. Adoral, side views of figured paratype USNM 170377 from the upper Dhruma Formation at locality KK9-112 showing the presence of only one large primary tubercle in each interambulacrum in a smaller specimen, $\times 4$.
4. Stereo-pair of same specimen showing the highly inflated apical system and the deep pits in each interambulacrum at the apical system, $\times 4$.
- 5-8. Views of a pyramid from USNM 170375 illustrated on Plate 5: figures 2-6, $\times 10$.

PLATE 7

Heterosalenia brocki Kier, new species:

- 1,2,3. Adapical, adoral, side views of holotype USNM 170378 from the Upper Jurassic, upper Dhruma Formation at locality S-1167, $\times 4$.
4. Adapical interambulacral region showing the extremely large primary tubercles of the same specimen, $\times 8$.
5. Apical view of same specimen showing knobs on genital and suranal plates and depressed suture, $\times 8$.
6. Adoral view of same specimen showing enlarged tubercles in ambulacra, lack of primary tubercles in interambulacrum, and slight gill slits, $\times 8$.

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PLATE 8

Heterosalenia brocki Kier, new species:

1. Ambulacrum and adjacent interambulacra at ambitus of holotype USNM 170378 from the Upper Jurassic, upper Dhruma Formation at locality S-1167 showing the sinuous ambulacra with small secondary tubercles of approximately the same size except for larger ones near poriferous zones, $\times 8$.
2. Ambulacrum near apical system of same specimen, $\times 8$.
3. Adoral view showing crowded porepairs at edge of peristome, enlarged ambulacral tubercles matching in size those of the interambulacra, $\times 8$.
- 4,5,6. Side, adapical, adoral views of figured paratype USNM 170379 from the upper Dhruma Formation at locality KK9-111 showing the plate sutures, $\times 4$.

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PLATE 9

Heterosalenia brocki Kier, new species:

1. Apical system of figured paratype USNM 170379 from the Upper Jurassic, upper Dhurma Formation at locality KK9-111, $\times 8$.

Heterosalenia dhrumaensis Kier, new species:

- 2,3,4. Adapical, side, adoral views of holotype USNM 170380 from the Middle Jurassic, middle Dhurma Formation at locality KK9-15, $\times 4$.

Pseudosalenia magniprocta Kier, new species:

- 5,6. Adoral, side view of figured paratype USNM 170381 from the middle Dhurma Formation at KK8-34, $\times 4$.
7. Apical system of figured paratype USNM 170382 from the middle Dhurma Formation at S-1160 showing apical system prolonged into the posterior interambulacrum, and presence of two suranal plates, $\times 14$.

PLATE 10

Pseudosalenia magniprocta Kier, new species:

- 1,2. Side and adapical views of holotype USNM 170383 from the Middle Jurassic, middle Dhruma Formation at KK8-30-35, $\times 5$.
3. Adapical interambulacral area of same specimen, $\times 10$.
4. Adapical ambulacral area of same specimen, $\times 10$.

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PLATE 11

Pseudosalenia magniprocta Kier, new species:

1. View of ambulacrum at ambitus of holotype (also figured on Plate 10) USNM 170383 from the Middle Jurassic, middle Dhruma Formation at KK30–35, $\times 10$.
2. View of interambulacrum at ambitus of holotype, $\times 10$.
3. View of ambulacrum at peristome of holotype, $\times 10$.
4. View of interambulacrum at peristome of holotype, $\times 10$.

Pseudocidaris raratuberculata Kier, new species:

5. Apical system of the holotype USNM 170384, from the Upper Jurassic, upper Dhruma Formation at KK9–111, $\times 10$.
6. Interambulacrum at ambitus showing extremely large tubercles with deeply depressed scrobicules, $\times 10$.

PLATE 12

Pseudocidaris raratuberculata Kier, new species:

- 1,2,3. Adapical, adoral, side views of holotype USNM 170384 from Upper Jurassic, upper Dhruma Formation at locality KK9-111, $\times 4$.
4. View of the sinuous ambulacrum at the ambitus of the holotype, $\times 10$.
5. View of ambulacrum adapically of holotype, $\times 10$.
- 6,7,8. Side, adapical and adoral views of figured paratype USNM 170385 from the upper Dhruma Formation at locality KK9-111, $\times 4$.

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PLATE 13

Pseudocidaris romani Kier, new species:

- 1,2,3. Adapical, adoral, side views of the holotype USNM 170386 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112.
4. Interambulacrum at ambitus of the holotype, $\times 8$.
5. Adapical view of an ambulacrum of the holotype, $\times 12$.

PLATE 14

Pseudocidaris romani Kier, new species:

- 1,2. Interambulacra and ambulacra at the edge of the peristome of the holotype showing the enlarged perforate secondary tubercles (for more photographs of this specimen see Plate 13),
× 8, 12.
3. Apical system of the holotype, × 12.
4. Ambulacrum at ambitus of holotype, × 12.

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PLATE 15

Pseudocidaris romani Kier, new species:

1. Apical system of figured paratype USNM 170387 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times 8$.
2. Adapical view of an ambulacrum and interambulacrum of the figured paratype USNM 170388 from the upper Dhruma Formation at locality KK9-112, $\times 8$.

Pseudocidaris depressa Kier, new species:

- 3,4,5. Adapical, adoral, side view of holotype USNM 170389 from the upper Dhruma Formation at locality KK9-21-21.5, $\times 4$.
6. Side view of interambulacrum of holotype, $\times 10$.

PLATE 16

Pseudocidaris depressa Kier, new species:

1. Apical system of holotype USNM 170389 from the Middle Jurassic, middle Dhurma Formation at locality KK9-21-21.5, $\times 10$.
2. Ambulacrum at ambitus of holotype, $\times 10$.
- 3,4. Adapical and side view of figured paratype USNM 170390 from the middle Dhurma Formation at locality KK9-21-21.5, $\times 4$.

Hypodiadema nanituberculata Kier, new species:

- 5,6,7. Adapical, adoral, and side views of holotype USNM 170391 from the Upper Jurassic, upper Dhurma Formation at locality KK9-112, $\times 4$.
- 8,9. Adapical and ambital views of ambulacrum IV of the holotype, $\times 10$. For a drawing of this ambulacrum see Figure 20a.
10. Apical system of the holotype, $\times 10$.

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PLATE 17

Hypodiadema nanituberculata Kier, new species:

1,2. Adapical and ambital views of interambulacrum of holotype USNM 170391 from the Upper Jurassic, upper Dhurma Formation at locality KK9-112, $\times$ 10. More photographs of this specimen are on Plate 16: figures 5-10.

Echinotiara arabica Melville:

3,4,5. Side, adapical, adoral views of hypotype USNM 170392 from the Lower Jurassic, Marrat Formation at locality S-1034, $\times$ 4.

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PLATE 18

Echinotiara arabica Melville:

1,2,3. Adapical, ambital, adoral views of ambulacrum of hypotype from the Lower Jurassic, Marrat Formation at locality S-1034 USNM 170393, $\times$ 8.

Polycyphus parvituberculatus Kier, new species:

4,5,6. Adapical, adoral, side view of holotype USNM 170394 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times$ 3.

7. View of interambulacrum at peristome of holotype, $\times$ 8.

8. Ambulacrum at ambitus of holotype, $\times$ 8.

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PLATE 19

Polycyphus arabicus Kier, new species:

- 1,2,3. Adapical, side, adoral views of holotype USNM 170395 from the Middle Jurassic, middle Dhurma Formation at locality KK8-46, $\times 3$.
4. Ambulacrum II at ambitus showing tuberculation of holotype, $\times 10$.
5. Ambulacrum II at peristome of holotype showing enlarged tubercles, $\times 10$.
6. Interambulacrum 3 at ambitus of holotype, $\times 10$.
7. Apical system of holotype, $\times 10$. A drawing of this area is on Figure 26.

PLATE 20

Polycyphus arabicus Kier, new species:

1. Interambulacral area at ambitus of figured paratype USNM 170396 from the Middle Jurassic, middle Dhruma Formation at locality KK8-46, $\times 10$.
2. Ambulacral area of same specimen at ambitus, $\times 10$.
3. Side view of same specimen, $\times 3$.
4. Adoral view of interambulacrum of holotype USNM 170395 from the middle Dhruma Formation at locality KK8-46, $\times 3$. More photographs of this specimen on Plate 19.

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PLATE 21

Polycyphus textilis Agassiz:

1,2. Side and adapical views of specimen from the Muséum National d'Histoire Naturelle figured by Cotteau 1880, pl. 482: figs. 5,6 from the Callovian at Marolles (Sarthe) in the D'orbigny Collection, $\times$ 3.

Polycyphus normannus Desor:

3,4,5. Adoral, adapical, side view of specimen from the Muséum National d'Histoire Naturelle from the Bathonian, Luc sur Mer (Calvados), $\times$ 4.

6,7. Ambulacral and interambulacral areas at ambitus of same specimen, $\times$ 12.

PLATE 22

Leioechinus amplius Kier, new species:

- 1,2,3. Apical, side, and adoral views of holotype USNM 170397 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times$ 2.
- 4,5. Adoral and side views figured paratype USNM 170398 from the upper Dhruma formation at locality KK9-112, $\times$ 3.
6. Ambulacrum at peristome of same specimen, $\times$ 6.
7. Apical system of figured paratype USNM 170399 from the upper Dhruma Formation at locality KK9-97-98, $\times$ 10.

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PLATE 23

Leioechinus namus Kier, new species:

- 1,2,5. Apical, adoral, and side views of holotype USNM 170402 from the Middle Jurassic, middle Dhruma Formation at locality KK8-33-35, $\times$ 4.
- 3,4. Views of ambulacrum V at ambitus and near peristome of the holotype, $\times$ 13.
6. Side view of figured paratype USNM 170403 from the middle Dhruma Formation at locality KK8-33-35, $\times$ 3. An oral view of this specimen is on Plate 24: figure 6.

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PLATE 24

Leioechinus namus Kier, new species:

- 1,2,3. Adapical ambital, adoral views of ambulacrum of figured paratype USNM 170404 from the Middle Jurassic, middle Dhruma Formation at locality KK8-35-38, $\times$ 10. Drawings of this area are on Figure 21a-c.
- 4,5. Adoral and side views of same specimen as above, $\times$ 3.
6. Adoral view of figured paratype USNM 170403 from the middle Dhruma Formation at locality 33-35, $\times$ 3.
- 7,8,9. Side, adapical, adoral views of small specimen figured paratype USNM 170405 from the middle Dhruma Formation at locality KK8-5-38, $\times$ 6.
10. Side view of figured paratype USNM 170406 from the middle Dhruma Formation at locality KK8-35-38, $\times$ 4. Note oyster spat indicating that echinoid remained uncovered on the sea floor and intact for sometime after its death.
11. Apical system of figured paratype USNM 170407 from the middle Dhruma Formation at locality KK8-30-35, $\times$ 12.

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PLATE 25

Acrosalenia bowersi Kier, new species:

- 1,2,3. Adapical, side, adoral views of holotype USNM 170409 from the Upper Jurassic, upper Dhruma Formation at locality S-1148, $\times$ 3.
- 4,5. Adoral and adapical portions of ambulacrum II of figured paratype USNM 170410 from the upper Dhruma Formation at locality S-1148, $\times$ 12. Further photographs of this specimen are on Plate 26: figures 1,2.

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PLATE 26

Acrosalenia bowersi Kier, new species:

1. Ambital view of interambulacrum of figured paratype USNM 170410 from the Upper Jurassic, upper Dhurma Formation at locality S-1148, $\times 12$.
2. Ambulacrum II of same specimen (rest of ambulacrum figured on Plate 25: figures 4,5, $\times 12$).

Acrosalenia somaliensis Currie:

- 3,4. Adapical and adoral view paratype E576 from the Hunterian Museum, Glasgow University, from the Bihen Limestone, British Somaliland, $\times 4$. Further photographs of this specimen are on Plate 27: figures 1,2.

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PLATE 27

Acrosalenia somaliensis Currie:

1. Side view of paratype E576 from the Hunterian Museum, Glasgow University, from the Bihen Limestone, British Somaliland, $\times 4$. Further photographs of this specimen are on Plate 26: figures 3,4.
2. View of interambulacrum at ambitus of same specimen, $\times 12$.

Acrosalenia marratensis Kier, new species:

- 3,4,5. Adapical, adoral, side views of holotype USNM 170411 from the Lower Jurassic Marrat Formation at locality S-1034, $\times 3$.
6. View of adapical interambulacral and adjacent ambulacral areas of same specimen, $\times 8$.
7. View of ambulacrum at ambitus of same specimen, $\times 12$. Another photograph of this specimen is on Plate 28: figure 1.

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PLATE 28

Acrosalenia marratensis Kier, new species:

1. Interambulacrum at ambitus of holotype USNM 170411 from the Lower Jurassic, Marrat Formation at locality S-1034, $\times$ 3. More photographs of this specimen are on Plate 27: figures 3-7.

Acrosalenia arabica Kier, new species:

- 2,3,4. Apical, side, and adoral views of holotype USNM 170412 from the middle Dhurma Formation at locality KK8-35-38, $\times$ 4.
5. Apical system of figured paratype USNM 170413 from the Middle Jurassic, middle Dhurma Formation at locality KK8-34, $\times$ 10.

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PLATE 29

Acrosalenia arabica Kier, new species:

1. View of ambulacrum II at ambitus of paratype USNM 170414 from the Middle Jurassic, middle Dhurma Formation at KK8-30-35, $\times 12$.
2. Ambulacrum I at peristome of same specimen, $\times 12$.
- 3,4. Ambulacrum III at apical system and at the ambitus of paratype USNM 170415 from the middle Dhurma Formation at locality KK8-35-38, $\times 15$.

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PLATE 30

Acrosalenia arabica Kier, new species:

1. Apical system of figured paratype USNM 170416 from the Middle Jurassic, middle Dhruma Formation at locality KK8-35-38, $\times$ 10.
2. Peristome of figured paratype USNM 170417 from the middle Dhruma Formation at locality KK8-35-38, $\times$ 8.
3. Interambulacrum at ambitus of same specimen, $\times$ 12.
4. Ambulacrum at ambitus of same specimen, $\times$ 14.

Acrosalenia pseudocidaroides Currie:

- 5,6. Side and adapical views of holotype E735 in the Hunterian Museum, Glasgow, from the Bihen Limestone, British Somaliland, $\times$ 3.

PLATE 31

Acrosalenia dhrumaensis Kier, new species:

- 1,2,7. Adapical, adoral, and side view of holotype USNM 170418 from the Middle Jurassic, middle Dhruma Formation at locality KK9-51.5, $\times 4$.
3. Ambulacrum I in adapical area of same specimen, $\times 12$.
4. Ambulacrum I at ambitus in same specimen, $\times 12$. A drawing of this area is on Figure 11b.
- 5,6. Interambulacrum at ambitus and adapical of same specimen, $\times 12$.
8. Apical system of same specimen, $\times 10$. A drawing of this area is in Figure 11a.

PLATE 32

Plesiechinus altus Kier, new species:

1. Apical system of holotype USNM 170419 from the Middle Jurassic, middle Dhruma Formation at locality L-921, $\times 7$.
- 2,3,4. Adapical, right side, adoral views of the holotype, $\times 2$.

Bothryopneustes arabica Kier, new species:

5. Peristomal region of holotype USNM 170420 from the middle Dhruma Formation at locality KK8-35-38, $\times 4$.

Bothryopneustes orientalis Fourtau:

6. Peristomal region of hypotype USNM 131268 from the Late Jurassic, Tuwaiq Mountain Limestone at locality S-1804, $\times 4$.

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PLATE 33

Bothryopneustes dhrumaensis Kier, new species:

- 1,2,3,4. Adapical, right side, rear, adoral views of holotype USNM 170421 from the Middle Jurassic, middle Dhruma Formation at locality KK8-33-35, $\times 2$.
5,6. Adapical, adoral views of figured paratype USNM 170423 from the middle Dhruma Formation at locality KK8-33-35, $\times 2$.

Bothryopneustes arabica Kier, new species:

- 7,9,10. Adapical, right side, adoral views of holotype USNM 170420 from the middle Dhruma Formation at locality KK8-35-38, $\times 1.5$. A more enlarged view of the floscelle of this specimen is on Plate 32: figure 5.
8. Rear view of figured paratype USNM 170424, one from the middle Dhruma Formation at locality KK8-35-38.

PLATE 34

Bothryopneustes inflata Kier, new species:

- 1,2,3. Adapical, right side, adoral views of holotype USNM 170426 from the Upper Jurassic, upper Dhruma Formation at locality KK9-100, $\times 2$.
4. Adoral view of figured paratype USNM 170427 from the upper Dhruma Formation at locality KK9-95-96, $\times 2$.
5. Adapical view of figured paratype USNM 170428 from the upper Dhruma Formation at locality KK9-112, $\times 2$.
6. Apical system of figured paratype USNM 170427 from the upper Dhruma Formation at locality KK9-95-96, $\times 15$.
7. Adoral view of figured paratype USNM 170429 from the upper Dhruma Formation at locality KK9-112, $\times 2$.

PLATE 35

Bothryopneustes kauffmani Kier, new species:

- 1,2,3,4. Adapical, adoral, left side, rear views of holotype USNM 170430 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times$ 2.5.
5. Tubercles on figured paratype USNM 170431 from the upper Dhruma Formation at locality KK9-112, $\times$ 27.
- 6,7. Adapical and adoral views of figured paratype USNM 170432 from the upper Dhruma Formation at KK9-112, $\times$ 2.5.

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PLATE 36

Bothryopneustes kauffmani Kier, new species:

1. Apical system showing the genital plates extending deeply into the interambulacra in figured paratype USNM 170431 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times 8$.
2. Adapical region in interambulacrum 3 showing the enlarged tubercles in the same specimen, $\times 8$.
- 3,4. Adapical and adoral views of same specimen, $\times 2$.
5. Floscelle of the same specimen, $\times 4$.

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PLATE 37

Bothryopneustes orientalis Fourtau:

1,2,3. Adapical, adoral, left side of hypotype USNM 131268 from the Upper Jurassic, Tuwaiq Mountain Limestone at locality S-1804, $\times$ 2.

4,5. Adapical, adoral views of hypotype USNM 170435 from the Tuwaiq Mountain Limestone at locality L-916, $\times$ 3.

PLATE 38

Bothryopneustes orientalis Fourtau:

1. Adapical view of hypotype USNM 170433 from the Upper Jurassic, Tuwaiq Mountain Limestone at locality L-916, $\times$ 2.
2. Adoral view of hypotype USNM 170434 from the same locality, $\times$ 2.
3. Adapical view of hypotype USNM 170435 from the same locality, $\times$ 2.

Pygurus arabicus Kier, new species:

- 4,5. Adapical, adoral views of the holotype USNM 170436 from the upper Dhurma Formation at locality L-926, $\times$ 1.
6. Floscelle of same specimen, $\times$ 3.
7. Phyllode of same specimen, $\times$ 5.

PLATE 39

Holactypus phelani Kier, new species:

- 1,2,3. Adapical, adoral, left side of holotype USNM 170437 from the Upper Jurassic, upper Dhruma Formation at locality KK9-112, $\times$ 2.5.
4. Ambulacrum I of figured paratype USNM 170438 from the upper Dhruma Formation at locality KK9-114, $\times$ 7.
5. Peristome of figured paratype USNM 170439 from the upper Dhruma Formation at locality KK9-96-97, $\times$ 7.

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PLATE 40

Holactypus phelani Kier, new species:

1. Adapical region of ambulacrum III of figured paratype USNM 170441 from the Upper Jurassic, upper Dhruma Formation at KK9-112, $\times 14$.
2. Interambulacrum 4 at the ambitus of same specimen, $\times 14$.
3. Ambulacrum IV midway between apical system and ambitus of same specimen, $\times 14$.
4. Interambulacrum 5 adpically of same specimen, $\times 14$.
5. Ambulacrum IV just below the ambitus of same specimen, $\times 14$.

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PLATE 41

Holactypus phelani Kier, new species:

1. Interambulacrum 4 midway between the apical system and the ambitus in figured paratype USNM 170441 from the Upper Jurassic, upper Dhruma Formation at KK9-112, $\times 14$.
2. Adoral view of figured paratype USNM 170440 from the upper Dhruma Formation at locality KK9-108.5, $\times 2$.
3. Adoral view of figured paratype USNM 170439 from the upper Dhruma Formation at locality KK9-96-97, $\times 2$.

Pseudocidaris sp.:

4. Spine USNM 170513 from the Middle Jurassic, middle Dhruma Formation at locality KK8-37, $\times 1$.
5. Spine USNM 170572 from the upper Dhruma Formation at locality KK9-113, $\times 1$.

Bothryopneustes inflata Kier, new species:

6. Rear view of figured paratype USNM 170429 from the upper Dhruma Formation at locality KK9-112, $\times 2$. For more photographs of this species see Plate 34.

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PLATE 42

Goniopygus superbus Cotteau and Gauthier:

1,2,3. Adapical, adoral, and side views of hypotype USNM 170442 from the Late Cretaceous, lower Aruma Formation at KK11, $\times 3$.

Actinophyma cf. *A. spectabile* Cotteau and Gauthier:

4,5,6. Adapical, adoral, and side view of hypotype USNM 170443 from the Aruma Formation at locality S-286, $\times 2$.

Coptodiscus nomiae Cotteau and Gauthier:

7,8. Adoral, adapical views of hypotype USNM 170444 lower Aruma Formation at locality S-748, $\times 2.5$.

9. Side view of hypotype USNM 170445 from the lower Aruma Formation at locality KK11, $\times 3$.

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PLATE 43

Coptodiscus nomiae Cotteau and Gauthier:

- 1,2. Adapical and adoral views of hypotype USNM 170446 from the Late Cretaceous, Aruma Formation at locality KK12, $\times 3$.
3. Lantern supports of hypotype USNM 170447 from the Aruma Formation at locality KK12, $\times 12$.
4. Interior of ventral surface of same specimen, $\times 6$.
5. Portion of adapical surface of hypotype USNM 170444 from the Aruma Formation at locality S-748.

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PLATE 44

Globator mortenseni (Checchia-Rispoli):

1,2,3,4. Adapical, right side, adoral, rear views of hypotype USNM 170448 from the Late Cretaceous, Aruma Formation at locality KK12, $\times 2.5$ except for figure 4 which is $\times 2$.

5,6. Adapical, right side of hypotype USNM 170449 from same locality, $\times 2.5$.

7. Peristome of hypotype USNM 170450 from same locality, $\times 7$.

PLATE 45

Rhynchopygus arumaensis Kier, new species:

- 1,2,3,4. Adapical, adoral, right side, rear views of the holotype USNM 170452 from the Late Cretaceous, Aruma Formation at locality KK11, $\times 3$.
5. Floscelle of same specimen, $\times 8$.
6,7. Adapical, adoral views of figured paratype USNM 170453, from same locality as holotype, $\times 3$.

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PLATE 46

Pygurostoma cf. *P. morgani* Cotteau and Gauthier:

1,2,3,4. Adapical, rear, right side, adoral views of hypotype USNM 170454 from the Late Cretaceous, Aruma Formation at S-71, $\times 1.5$.

Zuffardia cf. *Z. cerullii* Checchia-Rispoli:

5,6,7,8. Adapical, rear, right side, and adoral views of hypotype USNM 170455 from the Aruma Formation at locality S-71, $\times 2$.

Pygurus yamamaensis Kier, new species:

9,10,11. Adapical, front, adoral views of holotype USNM 170456 from the Lower Cretaceous, Yamama Formation at KK1-41, $\times 2$.

PLATE 47

Pygurus yamamaensis Kier, new species:

1. Peristomial region of holotype USNM 170456 from the Lower Cretaceous, Yamama Formation at KK1-41, $\times$ 4.
2. Peristome of figured paratype USNM 170457 from the same locality, $\times$ 15. Note the buccal spines which are rarely preserved on fossil echinoids.
3. Periproct of figured paratype USNM 170458 from the same locality, $\times$ 5.
4. Periproct of figured paratype USNM 170459 from the same locality showing a few periproctal plates, $\times$ 15.
5. Right side of the holotype, $\times$ 2.

Proraster granti Kier, new species:

6. Side view of holotype USNM 170461 from the Late Cretaceous, Aruma Formation at locality S-748, $\times$ 3.
7. Side view of figured paratype USNM 170460 from the same locality, $\times$ 3.

PLATE 48

Proraster granti Kier, new species:

- 1,2. Adapical and adoral views of the holotype USNM 170461 from the Late Cretaceous, Aruma Formation at locality S-748, $\times$ 3. A side view of this specimen is on Plate 47: figure 6.
- 3,4. Adapical and adoral views of figured paratype USNM 170460 from the same locality, $\times$ 3. A side view of this specimen is on Plate 47: figure 7.
5. Apical area of same specimen, $\times$ 20.
6. Petaloid area of holotype, $\times$ 5.

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PLATE 49

Iraniaster morgani Cotteau and Gauthier:

1,2,3,4. Adapical, front, right side, adoral views of specimen in the Muséum National d'Histoire Naturelle in Paris from the Senonian at Goulgoul, Arköwaz, Poucht-i-Koh, Louristan (Iran), $\times 1.5$. A more enlarged view of the peristome of this specimen is on Plate 50: figure 4.

Iraniaster douvillei Cotteau and Gauthier:

5,6,7,8. Adapical right side, rear, adoral views of lectotype (herein designated) from the École National Supérieure des Mines, Paris, from the Senonian of Louristan (Iran), specimen number C 101. This is the specimen in Cotteau and Gauthier's (1895) plate 5: figures 4–6, $\times 1.5$. A more enlarged view of part of a petal of this specimen is on Plate 50: figure 5.

PLATE 50

Iraniaster douvillei Cotteau and Gauthier:

- 1,2,3. Adapical, adoral, right side of lectotype of *Somaliaster magniventer* Hawkins F. 163 from the Sedgwick Museum, Cambridge, from the late Senonian of British Somaliland, $\times 2.5$.

Iraniaster morgani Cotteau and Gauthier:

4. Peristome of specimen figured on Plate 49: figures 1–4, $\times 16$.

Iraniaster douvillei Cotteau and Gauthier:

5. Part of a petal of the specimen figured on Plate 49: figures 5–8, $\times 11$.

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PLATE 51

Iraniaster affnimorgani Kier, new species:

- 1,2,3,4,5. Adapical, right side, front, adoral, and rear views of holotype USNM 170462 from the Late Cretaceous, Aruma Formation at locality KK11, $\times 1.5$.
6,7. Adapical and adoral views of figured paratype USNM 170463, $\times 1.5$.

PLATE 52

Iraniaster affnimorgani Kier, new species:

- 1,2. Adapical and right side of figured paratype USNM 170464 from the Late Cretaceous, Aruma Formation in cut on Khurais to Riyadh road at 78 km. marker, $\times 1.5$.
3. Rear view showing spines on figured paratype USNM 170465 from the Aruma Formation at KK11, $\times 4$.

Iraniaster affnidouvillei Kier, new species:

4. Enlarged view of petal I of figured paratype USNM 170466 from the Aruma Formation at KK11, $\times 10$.
5. Enlarged view of petal II of same specimen, $\times 10$.
- 6,7. Adapical, and adoral views of the holotype USNM 170467 from the same locality, $\times 1.5$.
A rear and side view of this specimen is on Plate 53: figures 3,4.

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PLATE 53

Iraniaster affinidouvillei Kier, new species:

- 1,2. Adapical and right side of figured paratype USNM 170468 from the Late Cretaceous, Aruma Formation in cut on Khurais to Riyadh road at 78 km. marker, $\times 2$.
- 3,4. Rear and left side of holotype USNM 170467 from the Aruma Formation at KK11, $\times 1.5$.
- 5,6. Adapical and left side of figured paratype USNM 170469 from the same locality, $\times 2$.

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PLATE 54

Iraniaster bowersi Kier, new species:

1,2,3. Adapical, right side, adoral views of the holotype USNM 170470 from the Late Cretaceous, Aruma Formation at S-1419, $\times$ 1.

4,5,6. Adapical, right side, adoral views of figured paratype USNM 170471 from the same locality, $\times$ 1.

PLATE 55

Schizechinus pentagonus Kier, new species:

- 1,2,3. Adapical, ambitus, adoral views of an interambulacrum of holotype USNM 170473 from the Miocene Dam Formation at S-126, $\times 6$.
4. Ambitus of ambulacrum of same specimen, $\times 6$.
- 5,6. Side and adoral views of same specimen, $\times 1.5$.

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PLATE 56

Schizechinus pentagonus Kier, new species:

- 1,2. Adapical and ambitus views of figured paratype USNM 170474 from the Miocene Dam Formation at locality S-126, $\times$ 3.
3. Adapical view of ambulacrum of same specimen, $\times$ 6.
- 4,5,6. Side, adoral, and adapical views of figured paratype USNM 170475, $\times$ 2.

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PLATE 57

Schizechinus duciei (Wright):

1. Ambulacrum at ambitus of specimen C. 12092 in the Sedgwick Museum, Cambridge, from the Upper Coralline Limestone in Malta, $\times 6$.

Opechinus costatus (D'Archiac and Haime):

- 2,3. Adoral, side views of hypotype USNM 170476 from the Miocene Dam Formation at S-360, $\times 6$.
4. View of ambulacrum at ambitus of same specimen, $\times 18$.
5. View of interambulacrum of same specimen, $\times 18$.

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PLATE 58

Opechinus costatus (D'archiac and Haime):

- 1,2. Adoral and side views of hypotype USNM 170477 from the Miocene Dam Formation at locality S-360, $\times$ 6.
- 3,4. Side and adapical views of hypotype USNM 170478 from the same locality, $\times$ 6.
- 5,6. Ambulacrum and interambulacrum at ambitus of hypotype USNM 170479 from the same locality, $\times$ 18.

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PLATE 59

Opechinus costatus (D'archiac and Haime) :

1. Apical system of hypotype USNM 170480 from the Miocene Dam Formation at locality 360, $\times 16$.

Fibularia damensis Kier, new species:

- 2,3,4. Adapical, right side, adoral views of holotype USNM 170481 from the Dam Formation at locality S-1392, $\times 7$.
- 5,6,7. Adapical, adoral, right side of figured paratype USNM 170482 from the same locality, $\times 7$.
- 8,9,10. Adapical, adoral, right side of figured paratype USNM 170483 from the same locality, $\times 7$.

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PLATE 60

Fibularia damensis Kier, new species:

1. Auricles of figured paratype USNM 170484 from the Miocene Dam Formation at locality S-137, $\times 16$.

Echinodiscus desori Duncan and Sladen:

- 2,3. Adapical and adoral views of hypotype USNM 170485 from the Dam Formation at S-532, $\times 3.5$.
- 4,5. Adapical and adoral views of hypotype USNM 170486 from the same locality, $\times 3.5$.
6. Periproct of same specimen, $\times 12$.

PLATE 61

Echinodiscus desori Duncan and Sladen:

1. Side view of hypotype 170485 from the Miocene Dam Formation at locality S-532, $\times$ 3.5.
Other views of this specimen are on Plate 60: figures 2,3.
2. Adapical view of specimen E724a in the British Museum (Natural History) and the Gaj Series, Sind, $\times$ 1.

Laganum tumidum Duncan and Sladen:

- 3,4. Adapical and adoral views of hypotype USNM 170487 from the Dam Formation near Jawan quarry just off the Ras Tanura road, Eastern Province, $26^{\circ}42'02''\text{N}$, $49^{\circ}58'04''\text{E}$, $\times$ 2.
- 5,6,7. Side, adapical, and adoral views of hypotype USNM 170488 from the same locality, $\times$ 2.
8. Adoral view of USNM 170489 from the same locality, $\times$ 2.
9. Adoral view of USNM 170490 from the same locality, $\times$ 2.

PLATE 62

Laganum tumidum Duncan and Sladen:

1. Adapical view of hypotype USNM 170891 from the Miocene Dam Formation near Jawan quarry just off the Ras Tanuar road Eastern Province, 26°42'02"N, 49°58'04" E. $\times$ 2.

Lovenia cf. *Lovenia elongata* (Gray):

- 2,3,4. Adapical, left side, adoral views of hypotype USNM 170492 from the Dam Formation at locality S-126, $\times$ 1.5.

Brissus latidunensis Clegg:

- 5,6. Adoral, and adapical views of hypotype USNM 170493 from the Dam Formation at locality S-126, $\times$ 2.
7. Adapical view of hypotype USNM 170494 from the same locality, $\times$ 2. An adoral view of this specimen is on Plate 63: figure 1.

PLATE 63

Brissus latidunensis Clegg:

- 1,2. Adoral and right side views of USNM 170494 from the Miocene Dam Formation at locality S-126, $\times 2$. An adapical of this specimen is on Plate 62: figure 7.
3,4. Right side, rear of USNM 170493 from the same locality, $\times 2$. Other views of this specimen are on Plate 62: figures 5,6.

Moiria adamthi Clegg:

- 5,6,7. Right side, adapical, adoral views of hypotype USNM 170496 from the Dam Formation at locality S-126, $\times 2.5$.
8,9. Right side and adapical view of hypotype USNM 170495 from the same locality, $\times 2$.

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PLATE 64

Agassizia powersi Kier, new species:

1,2,3. Adapical, rear, right side of holotype USNM 170497 from the Miocene Dam Formation at S-361, $\times$ 3.5.

4,5,6,7,8. Adapical, front, adoral, right side, and rear of figured paratype USNM 170498 from the same locality, $\times$ 4.

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PLATE 65

Agassizia powersi Kier, new species:

1,2. Adapical and right side of figured paratype USNM 170499 from the Miocene Dam Formation at S-361, $\times 8$.

Agassizia arabica Kier, new species:

3,4,5. Adapical, right side, adoral views of the figured paratype USNM 170500 from Eocene-Oligocene ?, locality S-761, $\times 3.5$.

6,7,8. Adapical, rear, adoral views of the holotype USNM 170501 from the same locality, $\times 3.5$. More photographs of this specimen are on Plate 66: figures 1-3.

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PLATE 66

Agassizia arabica Kier, new species:

1. Distal end of petal IV showing enlarged adoral porepairs at end of petal in holotype USNM 170501 from Eocene–Oligocene ?, locality S-761, $\times 11$.
- 2,3. Right side, front of same specimen, $\times 3.5$. More photographs of this specimen are on Plate 65: figures 6–8.

Echinodiscus ginauensis Clegg:

- 4,5. Adapical and adoral views of hypotype USNM 170502 from locality S-761, $\times 1.5$.

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PLATE 67*Eupatagus* species

- 1,2,3,4. Adapical, adoral, left side, front views of hypotype USNM 170515 from the Eocene–Oligocene ? at locality S-761, $\times$ 1.5.
- 5,6,7,8. Adapical, right side, rear, front views of hypotype USNM 170514 from the same locality, $\times$ 1.5.

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