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THE STUDENT'S HANDBOOK
OF
STRATIGRAPHICAL GEOLOGY

Martin A Peacock.

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THE STUDENT'S HANDBOOK

OF

STRATIGRAPHICAL GEOLOGY

BY

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EDITED BY
SECOND EDITION

ILLUSTRATED WITH MAPS, DIAGRAMS, AND FIGURES OF FOSSILS

LONDON: EDWARD STANFORD

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PREFACE

IN preparing a new edition of this volume I have not only revised and partly rewritten the descriptions of the British strata, but have enlarged the scope of the work by giving more complete accounts of the continental representatives of each system or series of rocks. I have, however, strictly confined myself to the geology of Europe, because any adequate account of Asiatic or American strata, with their fossil contents, would have made the volume too bulky. For such further information the student must consult a larger treatise, such as Sir A. Geikie's *Text-book of Geology* or de Lapparent's *Traité de Géologie*.

It has often been said that the British Isles present us with an epitome of the geology of Europe; but though it is true that we possess representatives of nearly all the great series of strata which form the geological record, yet some of them are missing, such as the Stephanian Series, the Middle Trias (Muschelkalk, etc.), and the Miocene (except for the Bovey Beds), while others consist of freshwater deposits instead of the more universal marine facies. Consequently, a student who is only acquainted with the British rocks is ignorant of many important formations and fossils, and is apt to take limited and incomplete views of the stratigraphical systems and their problems.

In thinking it desirable to supply such supplementary

information I am supported by many teachers of geology, who wish their students to take a broader view and to learn more about the geology of Europe, with perhaps less local detail of English subdivisions and zones. In order to show how such wider knowledge can be utilised and made interesting, I have appended to each chapter a brief sketch of the conclusions which may be drawn from the facts with regard to the physical and geographical conditions under which each great series of strata was accumulated in the European region.

Further, in three cases I have ventured to express these conclusions in the form of cartographical restorations, *i.e.* of the Lower Devonian, the Upper Trias, and the Lower Cretaceous. Such maps form a conspicuous feature in the later editions of de Lapparent's treatise, but have not yet been inserted in an English text-book. In a future edition I may be able to include maps of other epochs; meantime, I would suggest that students should endeavour to make their own geographical restorations from the descriptions which I have given. I need hardly seek to justify such advice, for, as Professor Watts has remarked, such maps "group together numbers of facts and inferences with which it was previously difficult to retain touch;" . . . they "systematise future research, they direct to the places where the discovery of new facts is desirable."

In the work of revision I have sought the assistance of those geologists who have paid special attention to particular formations. Their writings are, of course, referred to in the text, but I have to thank the following friends and correspondents for reading portions of certain chapters, and for useful information thereon:—C. T. Clough, Edward Greenly, W. G. Fearnside, J. E. Marr, A. Vaughan, E. A. Newell

Arber, T. G. Bonney, and H. Woods. I am specially indebted to Mr. Woods for revising all the descriptions and lists of fossils, and for amending the nomenclature, both of genera and species, in accordance with current views.

Finally, I may point out that many additional illustrations have been inserted, not only of fossils but of maps and sections, so that there are now over two hundred figures and groups of fossils. Moreover, two of the older maps, those of North Wales and Devonshire, have been replaced by more correct representations, in accordance with recent publications.

A. J. JUKES-BROWNE.

WESTLEIGH, TORQUAY,
November 1911.

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CHAPTER I

THE SUCCESSION OF STRATIFIED ROCKS

Scope of the Subject.—In some manuals of Geology this branch of the subject is called Stratigraphical Geology, because it chiefly consists in the description of the great stratified series of rocks which make up the mass of the earth's crust. It is sometimes called historical geology because it should comprise not only a description of the various rocks which were formed during each period of the world's history, but also some description of the fossils found in each formation, and some account of the physical conditions under which the rocks themselves were deposited, with a notice of the changes in the relative position of land and sea which took place from time to time; all this should be made as complete as the imperfection of the geological documents will allow.

In brief, historical geology should gather up the knowledge acquired in all the other departments of the science, and should apply it to the elucidation of the history of the earth, or of a portion of the earth, from the earliest time of which any records exist down to the time of human history.

At present there are only a few limited areas of the earth's surface about which we have anything like a full stratigraphical knowledge, and much remains to be learnt even in the areas about which we know most. Historical geology, therefore, is yet in its infancy; but enough is now known of the stratigraphical geology of Europe to make it possible to give an outline of its geological history, and American geologists are rapidly making it possible to do the same for North America.

The Succession of Stratified Rocks.—The general principles on which stratigraphical geology is founded are easily understood, and the manner in which the order and succession of rock-groups is established will now be briefly explained. The mere succession of strata in any district or country, however, is

one thing, and the grouping of such strata into larger systems, representing definite geological periods, is another thing, and one which requires consideration from several points of view. A subsequent chapter, therefore, will be devoted to a discussion of the principles upon which divisional lines may be drawn in any established succession of rock-groups.

The two principal tests by which the relative age of different strata is determined are—(1), Superposition ; (2), Fossil contents.

The conclusions to be drawn from the superposition of strata are explained in most text-books of physical geology, and the law of vertical succession which forms the basis of the whole fabric of historical geology may be stated as follows:—"In any succession of beds each one represents the conditions which prevailed over a certain area for a certain length of time, the lowest is the oldest, the uppermost is the newest, and the relative age of the others is indicated by their relative position." If the strata are inclined, the right order is ascertained by making a geological survey of the district, and constructing a section at right angles to the general strike of the beds.

Again, by tracing any one set of strata horizontally along their strike from one part of a district to another, where perhaps there are other rocks of a different kind, we obtain a datum of reference by which to determine whether the rocks in the second area are newer or older than those in the first.

So long as there is physical and geological continuity between the different portions of a district, *i.e.* so long as some one member of a conformable series of strata can be followed continuously, such a survey generally affords sufficient data for ascertaining the relative position of the rocks which occur in the district, and for constructing a table of their vertical succession. But when either geographical or geological continuity is interrupted—that is, when a district or country is separated from others of like structure either by the sea or by tracts of totally different rocks—then we must begin all over again, and construct an independent table of strata for the new district. For example, Wales is a district to all parts of which one system of classification and nomenclature can be applied. Similar groups of rocks occur in Ireland on the one hand, and in Cumberland on the other ; but Wales is physically separated from Ireland by the Irish Sea, and geologically separated from Cumberland by the Triassic plains of Cheshire and Lancashire ; hence the same system of nomenclature could not be used in the other districts, the vertical succession had to be determined independently, and local names given to the different subdivisions in each district before they could be in any way compared with one another.

But, it may be asked, when two such districts have been independently investigated, how are we to correlate the two tables of strata, and ascertain which rocks or rock-groups were approximately contemporaneous? It is here that a knowledge of fossils (Palæontology) comes to our aid, and enables us to identify rocks by their fossil contents, so that strata in different districts and of different lithological characters may be included in the same natural group or system, because they contain the same or closely similar species of fossils. This was the principle discovered and applied at the beginning of last century by Dr. William Smith, who is often called the Father of British Geology, and who was certainly the founder of that branch of the science which is the subject of the present volume.

The book in which Smith recorded his discovery of the stratigraphical use of fossils was entitled *Strata identified by Organised Fossils*, and was published in 1816. He had previously made out the succession of the strata which occur near Bath, and had observed that each well-marked group of beds contained a special assemblage of fossils. As his acquaintance with English rocks became larger he noticed that there was a similar succession elsewhere, and thus (in the words of his nephew and biographer¹) "he inferred that each of the separate periods occupied in the formation of the strata was accompanied by a peculiar series of the forms of organic life, that these forms characterised those periods, and that the different strata could be identified in distant localities and otherwise doubtful cases by peculiar embedded organic remains."

The experience of subsequent observers confirmed and established this inference, which has become a guiding principle in stratigraphical geology. Further research, moreover, has brought out the more definite conclusion that there has been a continuous succession of life-forms, that species and genera and families, and even whole orders of beings, have come into existence, have flourished, and have then gradually died out, never to recur. It is this *non-recurrence* of species which gives a special value to fossils as a test of age and as a means of correlation. The same kind of rock has been formed again and again during the history of the world, but when once a species has died out it has never appeared again.

It must not be supposed, however, that the stratigraphical succession of rocks presents us with a complete record of the history of the earth, or that it will ever supply us with examples of all the species which have lived upon the earth's surface. On the contrary, the records preserved to us are very incomplete, and many pages are wanting in every chapter of the great volume, so

¹ *Memoirs of William Smith*, by John Phillips, F.R.S., 1844.

that historical geology cannot be defined as a complete *History of the Earth*; it would be more correctly described as *Scenes from the History of the Earth*.

Nomenclature of Rock-groups.—As soon as it was recognised that the rocks which compose the earth's crust were not a mere congeries of rock-masses without order or sequence, but that when properly interpreted they arranged themselves in an orderly succession of formations, then it was seen to be necessary that names should be given to all parts of this wonderful succession of stratified deposits.

The history which can be read from the "records of the rocks" is a very long one, although, as has already been stated, it is by no means a complete history. Every natural region of the earth's surface has its own geological history, but the same great periods of time can be recognised in all. Geological history, like human history, has its early or pristine times, its mediæval times, and its later or more modern times; it may perhaps be said to consist of several volumes, and of course each of these volumes consists of several chapters dealing with so many successive periods.

Stratigraphical nomenclature is not very satisfactory, for it has been gradually developed in a synthetic manner, and is not the consistent and harmonious arrangement which it might have been had the older geologists possessed our present knowledge of the rocks. In early days the greater rock-groups were generally called *formations*; thus we read of the Old Red Sandstone formation, the New Red Sandstone formation, the Carboniferous formation, and the Chalk formation. Afterwards, as a knowledge of their fossil contents increased, the relative time-values of these formations were better understood, and some of them were united with others to form systems, but the number of such systems was not fixed, nor did any definite idea exist as to what entitled a series of rocks to rank as a system. There is still some difference of opinion on this point, but doubtless agreement will ultimately be attained.

It was also early perceived that the older formations differed very greatly from the later deposits both in mineral characters and in fossil contents. It was noticed that the oldest rocks were generally crystalline schists, that the next oldest were more or less altered and indurated, while the later were often soft and clearly stratified, and the most recent were usually loose and unconsolidated. Hence Werner in Germany used names which may be translated as equivalent to *primitive*, *transition*, *stratified*, and *alluvial* rocks, and the French introduced the more convenient terms *Primary*, *Secondary*, and *Tertiary* divisions.

It was supposed that the rocks belonging to these eras of time

differed essentially in their original nature and mode of formation. Subsequent investigation proved this idea to be an error, and Professor Phillips consequently proposed another set of names based on palæontological facts, namely, *Palæozoic*, *Mesozoic*, and *Cænozoic*, signifying respectively times of ancient, middle, and recent life. The two former of these have been very generally adopted, but Tertiary is still preferred to Cænozoic, and there is no reason now why its correlatives, Primary and Secondary, should not be employed as time-words, instead of the more cumbrous Palæozoic and Mesozoic.

Professor E. Forbes thought that the faunas of the Secondary and Tertiary had so great an affinity that the whole succession was more naturally divisible into two eras, which he termed Palæozoic and Neozoic. No doubt this is strictly correct, but the triple division has been found very convenient in Europe, and is more generally adopted.

Since these terms were proposed, however, a series of stratified rocks has been discovered below those which were called Primary or Palæozoic, and for these several names have been proposed. Of these *Archæan* is the best, for pre-Cambrian is too indefinite, and the others, *Azoic* and *Eozoic*, are founded on the respective assumptions (1) that they contain no organic remains, (2) that they contain the relics of the first dawn of life in the world. Such small traces of life as have been discovered in these rocks do not suggest anything very different from that of Palæozoic time, but they may for the present be termed Eozoic.

In the following table of systems the oldest is placed at the bottom and the newest at the top to indicate their natural superposition and order in the chronological scale.

Eras.	Systems.	
Tertiary or Cænozoic	{ Neogene.	} <i>Quaternary</i> } <i>Pliocene</i> } <i>Miocene</i> } <i>Oligocene</i> } <i>Eocene</i> } <i>Cænozoic</i>
	{ Paleogene.	
	{ Cretaceous.	
Secondary or Mesozoic	{ Jurassic.	
	{ Triassic.	
	{ Permian.	
	{ Carboniferous.	
Primary or Palæozoic	{ Devonian.	
	{ Silurian.	
	{ Ordovician.	
	{ Cambrian.	
	{ Eparchæan.	
Archæan or Eozoic	{ Mesarchæan.	
	{ Protarchæan.	

Nomenclature.—With regard to the names of the systems in the above table some explanation is required. Such names as

Carboniferous and Cretaceous are used in a far wider sense than their mere lithological signification. These names were originally given to certain British formations, in which the most conspicuous elements were respectively beds of coal and chalk; but they have since acquired a chronological meaning, and are used as systematic names for the periods of time during which the rocks were formed. They have also been adopted in other countries for rock-groups, which occupy the same relative place in the geological succession.

The Cretaceous System then includes, not only the Chalk, but also the underlying beds of sand and clay, which contain a similar assemblage of genera and species. Moreover, the Cretaceous System includes not only the Chalk and its associated beds in Europe, but all the rocks which were formed during the same period of the earth's history. Elsewhere, therefore, as in North America, the system may consist of sandstones, shales, and coal-seams without a bed of real chalk in it.

So the Carboniferous System means that system of strata of which the *British* Coal-measures form an integral part, but which includes several other rock-groups, all united by a community of fossils. It is these fossils, and not the occurrence of coal-seams, which are the criterion of the so-called Carboniferous period, for, as above mentioned, in America there are coals of Cretaceous age. In the same way, when we speak of the Carboniferous Limestone Series, we do not mean a group which everywhere consists of limestone, but one to which the great Carboniferous limestone belongs; when traced northward through England, this limestone is found to split up into separate beds, which finally become subordinate to thick masses of sandstone and shale.

The Devonian System is now considered to include the great series of rocks which are still called the Old Red Sandstone. This is a particularly awkward and unsatisfactory name for an important group of rocks. It was called *old* because it lay beneath the Carboniferous rocks, above which came another group of similar red sandstones. The latter were formerly termed New Red Sandstone, but this has been divided into two distinct systems which have received appropriate names, and it is to be hoped that "Old Red Sandstone" also will soon be replaced by a better name. As Jukes observed fifty years ago,¹ "it is avowedly a provisional designation, just exactly as the names of all the great groups of stratified rocks are provisional. They are temporary names adopted for present purposes, and have grown into use, and will continue to be used until they are superseded by more appropriate terms, which increasing knowledge only can show to be more appropriate."

¹ *Manual of Geology*, second edition, 1862, p. 429.

In many respects those names which have a geographical or historical origin are the most satisfactory—names taken from those of towns, rivers, mountain ranges, provinces, or the ancient races which inhabited such provinces; as Jurassic (from the Jura range), Devonian (from the county of Devon), Cambrian (from the Roman name of North Wales), Silurian (from the tribe of the Silures). These will probably remain as permanent names for systems to which they are applied.

Definition and Delimitation of Systems.—The number of systems into which the geological series should be divided, and the horizons at which the planes of separation are placed, are points requiring some consideration, because they involve certain principles of classification. The divisional lines are generally drawn where natural breaks occur, either in the sequence of the strata themselves, or in the succession of fossil species which they contain. Such breaks are therefore of two kinds, (1) Stratigraphical, (2) Palæontological.

1. *Stratigraphical Breaks.*—The nature of stratigraphical breaks or unconformities is explained in all handbooks of physical geology, and in the present connection we have to deal only with their relative importance and value in classification. The most complete and satisfactory measure of any unconformity is the thickness of strata which were deposited in other areas during the time represented by the gap between the two unconformable formations.

It is not every unconformity which is of sufficient importance to form a plane of division between two systems. Thus in Wales there is a great local unconformity within the Silurian System, but this does not exist in other areas. Again, in Northampton and Lincolnshire there is unconformity between two portions of the Jurassic System, while no such break exists either in the south of England or in Yorkshire.

A break which is represented elsewhere by several thousand feet of rock implies the lapse of a considerable period, and being always accompanied by a great change in the fossils, might be taken as a line of division between two systems. But if systems were to be rigidly limited by physical unconformities, and defined as a series of beds formed during a complete oscillation of downward and upward movement, the classification of the rocks in one area will break down when applied to those of other districts, because the gaps will occur at different horizons in different areas. Thus in Britain alone three different classifications at least would be required for the Primary rocks, as the following columns will show, a — being taken to mean a break or unconformity.

South Wales.	North Wales.	Scotland.
Carboniferous.	Carboniferous.	Carboniferous.
Upper O.R.S.	—	Upper O.R.S.
Middle O.R.S.	—	—
Lower O.R.S.	—	Lower O.R.S.
Silurian.	Silurian.	Silurian.
—	—	—
Ordovician.	Ordovician.	Ordovician.
—	—	—
Cambrian.	Cambrian.	Cambrian.

Thus, if we adopted the arrangement warranted by the stratigraphical breaks which occur in South Wales, we should have two separate systems, and two only, for there is a general conformity between the Cambrian and Ordovician, and from the Silurian to the Carboniferous.

In North Wales, however, the break between the Ordovician and Silurian is much less marked, while there is certainly one above the Cambrian, and there is an entire absence of Old Red Sandstone, so that we should make three separate systems. Again if we pass to the south of Scotland we find complete conformity between the Ordovician and Silurian, and no marked break between the latter and the Old Red Sandstone, but a great one between the two divisions of this Red Sandstone formation. Hence we might also make three systems in Scotland, but they would be quite different from those in Wales and would be of very unequal value.

As in this case, so also in others, a classification founded on physical breaks may be conveniently used for a limited district, and until further knowledge is acquired; but the breaks in the succession are certain to be filled up elsewhere by transitional beds, and as these may be of systematic value, we must always be prepared for the possible intercalation of another system between any two groups that are divided by a decided unconformity.¹

In brief, it must be admitted that unconformities are *geological accidents*, and if our classification and nomenclature are to be applicable to any large section of the earth's crust, they must be based, not on stratigraphical but on palæontological facts. The Ordovician, Devonian, and Jurassic are systems so established; and, in process of time, as our knowledge becomes more and more complete, it is probable that the number of systems will be finally determined in the same manner. They will always be more or less arbitrary divisions, since it will be difficult to say what number of

¹ The student can read with advantage Professor Lapworth's article on the "Classification of the Lower Palæozoic Rocks" in the *Geological Magazine*, Dec. 2, vol. vi. p. 1 (1879).

peculiar genera would entitle a series of beds to the rank of a system ; but a general agreement will doubtless be reached in time. Meanwhile the student will do well to regard our present classification as provisional, and to remember that, though divisional lines must be drawn somewhere, passage beds and transition groups are of frequent occurrence in nature.

2. *Palæontological Evidence*.—But although we must rely mainly on palæontological evidence in separating one system from another, it must not be supposed that every sudden change of fauna is to be taken as introducing a new system, or that such a change always indicates a period of non-deposition, and therefore a greater or less break in the succession ; unless this coincides with a physical break, the mere fact of such a change does not necessarily prove any great lapse of time. The change may be caused in several ways, either by rapid depression, by a sudden immigration of new forms, or by elevation with or without continuous deposition.

It is conceivable, for instance, that rapid depression, causing a considerable increase in the depth of the water, and removing the area farther away from the coast line, would produce what has been termed a palæontological break in a comparatively short period of time, and without any discontinuity of deposit. The beds below a certain plane would embed the remains of a shore fauna, while those above it would contain a deep-water assemblage, which might be very different even if the deposits were of similar lithological character. Depression, by the submergence of barriers, may also cause much more extensive changes ; we have only to consider what would result from the submergence of certain existent isthmuses, such as those of Panama and Suez, to realise what must have repeatedly happened in the past. The balance of life in both provinces would be altogether disturbed and upset, resulting in the extinction of some forms, the inter-migration of others, and the development of some new varieties and species.

Moreover, an alteration in the physical geography of one area may indirectly, but very greatly, affect the climate and life of another distant area ; thus, if the whole isthmus of Panama were now to be submerged, the Gulf Stream would probably be diverted from its present course, the result of which would be an immediate refrigeration of the British climate and a consequent immigration of Boreal and Arctic species into the Celtic province. Again, if the Gulf Stream remained, but the opening into the Arctic ocean were closed, the British climate would be ameliorated, Boreal forms would disappear, and a more southern assemblage would occupy the area.

Elevation of the sea-bottom will produce similar direct changes

to those caused by depression; a deep-sea area, where deposition has been very slow, may by elevation be brought nearer to a coast line, and beds containing a deep-sea fauna may be succeeded immediately by others more rapidly accumulated, and embedding a shallow-water assemblage. The change of life in such a case would be great, but the lapse of time would not be correspondingly long. If, however, elevation is continued till the area is raised above the sea-level, and remains for a time as a land surface, then a plane of erosion will be formed, and the change of fauna will be accompanied by stratigraphical discontinuity. The break then may be very considerable, but it may or may not coincide with the epoch of change from one fauna to another in an adjacent area of subsidence.

Notwithstanding this, it is true that the continuity of deposition may outlast the duration of a certain fauna; and it may become necessary to draw a line between two faunas of systematic importance in the midst of a conformable series of strata; in such a case it will naturally be drawn where the greatest palæontological break occurs. In other words, a life-assemblage, characteristic of one period in the world's history, may continue to inhabit any area until such changes occur as to cause the introduction of an assemblage which has been gradually developed outside that area, and these changes may take place with or without interruption of deposition in that particular area.

From the preceding remarks it will be seen that it is impossible to define a system as a series of deposits formed during one complete downward and upward movement or oscillation of some one part of the earth's surface. Moreover, if we could so define a system, the systems of one region could not be coeval with those of other regions. Systems must therefore have a palæontological value, and a system may perhaps be defined as a consecutive series of strata formed during the prevalence of certain generic forms of life throughout a large part of the earth's surface.

The student must be prepared to find that systems founded on the differences in successive faunas will not include anything like equal thicknesses of rock. If, as appears most probable, the differentiation of species and the development of higher forms has progressed in a constantly increasing ratio, it is clear that the time-value of systems based on such changes will become less and less as we approach modern times. It is certainly a fact that the same forms of life extend through a much greater thickness of rock in the earlier than in later geological times; and there is no reason for supposing that the production of rocks went on more rapidly (at any rate during later Palæozoic periods) than at the present time; limestones must always have been of slow and

gradual growth, and yet the persistence of species through the Carboniferous Limestone Series is truly remarkable, while the limestones of the Jurassic and Cretaceous periods, though of far less thickness, are divisible into numerous palæontological zones or belts, each having many species which do not appear in the next. The changes in the forms of life inhabiting any marine area being thus more rapid in later geological times, an equal amount of change would naturally be accomplished in less time, and consequently, if systems are to be measured by palæontological difference, the newer systems must include less thicknesses of rock.

But even when allowance is made for this, it is impossible to regard the divisions of Tertiary time introduced by Sir Ch. Lyell as being of the same relative importance as the systems of older date with which they are usually ranked. Even the Eocene, as understood by Lyell, was hardly of the same palæontological value as Cretaceous or Silurian, while the Miocene and Pliocene are still less entitled to rank with such systems. The Oligocene has been created at the expense of Lyell's Eocene, but it is now admitted that these two together form a group which may rank as a system, while the remaining three groups, Miocene, Pliocene, and Pleistocene, may be regarded as making up another system of deposits. For these two systems M. Hohnes has proposed the names *Palæogene* and *Neogene*, and though they are not altogether satisfactory the names have been largely accepted on the European continent.

Systems are divided into sections or formations, which are usually denominated as Upper, Middle, and Lower, unless any special names have been proposed for them. These sections are again divided into stages or groups, to which local names are generally given, and these again are often divisible into zones.

The following is a tabular view of the twelve fossiliferous systems which overlie the Archæan rocks, together with their primary divisions, according to the nomenclature which will be adopted in this volume, and is applicable to the greater part of Europe. This list of systems is merely a table from which no idea of relative thickness can be obtained, but the adjoining columnar view is drawn to scale and is intended to give some idea of the relative thicknesses of these systems.

Systems.	Primary Divisions.	Relative Thickness.	
NEOGENE .	{ Pleistocene. Pliocene. Miocene.	NEOGENE	
		PALÆOGENE	
		CRETACEOUS	
PALÆOGENE .	{ Oligocene. Eocene.	JURASSIC	
CRETACEOUS .	{ Upper. Lower.	TRIASSIC	
JURASSIC .	{ Upper (White Jura). Middle (Brown Jura). Lower (Lias).	PERMIAN	
		CARBO- NIFEROUS	
TRIASSIC .	{ Keuper. Muschelkalk. Bunter.		
PERMIAN .	{ Magnesian Limestone (Zechstein). Red Sandstone (Rothliegende).	DEVONIAN	
CARBONIFEROUS	{ Stephanian. Westphalian (Coal-Measures). Avonian (Carboniferous Limestone).	SILURIAN	
DEVONIAN .	{ Upper. Middle. Lower.	ORDOVICIAN	
SILURIAN .	{ Downtonian or Ludlow Beds. Salopian or Wenlock Beds. Valentian = Llandovery Beds.	CAMBRIAN	
ORDOVICIAN	{ Bala Series. Llandilo Series. Arenig Series.		
CAMBRIAN	{ Upper (Olenian). Middle (Paradoxidian). Lower (Olenellian).		

The actual thickness of any system of strata varies of course in different parts of the same country, and for the construction of the diagram the full average thickness of each stage has been taken from English districts where the whole system is well developed. The diagram does not, therefore, show the maximum thickness of any system. Moreover, in other parts of the world the Permian and Triassic Systems are represented by marine deposits which reach a thickness of 9000 to 10,000 feet.

Further, the Neozoic division is much thicker on the European continent than it is in England, for in the Alps thick deposits come in between the Triassic and Jurassic Systems, and the Neogene Series is of much greater thickness in Southern Europe than it is in the north.

CHAPTER II

STRATIGRAPHICAL PALEONTOLOGY

It was stated on p. 3 that ever since the surface of the earth became a fit habitation for plants and animal life there has been a succession of life-forms, and that remains of these faunas are found as fossils in the stratified rocks. It was also stated that this succession was incomplete owing to gaps in the series. The causes which have produced this imperfection of the record may now be indicated, so that the reader may understand what kinds of creatures are likely to occur as fossils and what are not. It will also be shown that, where the succession is continuous and fossils are fairly abundant, they can be used for the establishment of smaller subdivisions of the series and for the comparison of such subdivisions in different areas. Finally a few words on the distribution of species at the present day will explain some limitations in the application of palæontological evidence, and the difference between *synchronism* and *homotaxis* in correlating the rock-groups of different countries.

Origin of Species.—At the outset of this inquiry we are met by the question, What is a species? Before the publication of Darwin's book on the *Origin of Species* most people regarded a species as the result of a special creation of a definite kind of plant or animal, yet all who studied either plants or animals were obliged to admit that some species displayed many varieties, and also that it was difficult to say what amount of difference should constitute a species.

Lamarck in 1801 was the first to propound the doctrine that all existing species are descended from other species, but few naturalists gave credence to his views, and it was not till 1859, when Darwin published his book, that the world became familiar with such a doctrine.

On the primary point of the appreciation of differences Darwin remarks (*Origin of Species*, sixth edition, p. 41), "Certainly no

clear line of demarcation has as yet been drawn between species and sub-species—that is, the forms which in the opinion of some naturalists come very near to, but do not quite arrive at, the rank of species; or again between sub-species and well-marked varieties, or between lesser varieties and individual differences; and a series [of specimens] impresses the mind with the idea of an actual passage.” Further on he says, “From these remarks it will be seen that I look at the term species as one arbitrarily given, for the sake of convenience, to a set of individuals closely resembling each other, and that it does not essentially differ from the term variety, which is given to less distinct and more fluctuating forms.”

Darwin and Wallace developed their views about the same time, and both accounted for the existence of so many varieties, species, and genera of organisms by indicating the various causes and conditions which influence all kinds of organisms and tend to modify their habits, forms, and members. They have shown how the constant struggle for existence and the frequent changes of environment may have developed or have increased a tendency to variation, and how this variation results in the formation of varieties and species. Natural selection (or the selective action of natural processes) results also in the extinction of many forms and in the survival of a few—namely, of those few which are the most capable of accommodating themselves to the more rigorous and changed conditions of existence. This is called the “survival of the fittest.” It is by the infinite repetition of these processes that species which are now widely different may have been evolved from a common ancestor.

Another consequence of natural selection is the preservation of those varieties and species which chance to possess peculiarities that are useful to them in the struggle for existence. Thus as Darwin says (*op. cit.* p. 103), “it leads to the improvement of each creature in relation to its organic and inorganic conditions of life, and consequently in most cases to what must be regarded as an advance in organisation.” In other words, it leads to the evolution of higher and higher forms of life.

Now if the descendants of varieties may become different species, and if the descendants of different species may in course of time become so differentiated that most naturalists would rank them as different genera, and if this process has been going on during the whole of geological time, since the world first became fit to support life; then we might expect that the successive assemblages of fossils preserved for us in the rocks of the earth's crust would furnish us with a long succession of links between one

species and another, and would connect the generic forms of the present with those which have long been extinct. Unfortunately, however, though many such links have been found, and though more come to light every year, so that the genealogy of many genera can be satisfactorily made out, yet there are reasons why we can never hope to find all the links in the chain.

Imperfection of the Geological Record.—That the truth of Darwin's theory of the origin of species cannot at once be proved, and the complete genealogy of modern genera be constructed from the records of the past, is due to the imperfection of that very geological record which would otherwise contain the obvious proof or refutation of the hypothesis. This imperfection results from two causes, (1) the conditions which limit the entombment and preservation of organic remains, (2) the frequent erosion and destruction of the deposits in which they have been buried.

1. *Conditions of Entombment.*—If we consider the manner in which deposits are now taking place, we shall perceive that the preservation of many kinds of organic remains in these deposits is likely to be an exceptional and accidental occurrence. Deposition of sediment is not an uninterrupted process likely to ensure the conservation of specimens of the greater number of plants and animals living at any one time, but is, on the contrary, so discontinuous that only a small proportion of any fauna or flora would be entombed in such a way as to be permanently preserved, either in terrestrial or marine deposits.

On land, generations of animals may die and moulder away, shells, bones, and all, without any remains being transported to places where deposits are accumulating. Mr. F. C. Selous remarks that in South Africa "no organic matter lasts very long when exposed to the weather, and even the skull and leg bones of an elephant would, I think, crumble to dust and absolutely disappear in less than fifteen years from the date of the animal's death."¹ In some countries where the climate is very dry they may last longer, but still ultimately decay and crumble into dust.

Of the larger land animals a few are occasionally buried in bogs or drowned in lakes and rivers, and still fewer are carried down by rivers to the sea. The animals which live in fresh water and the leaves of plants stand a better chance of preservation in those parts of the country where lacustrine and fluviatile deposits are being formed; but these purely freshwater beds occupy but small areas, and are particularly liable to subsequent destruction, so that as a rule our knowledge of the terrestrial and fluviatile fauna of any period is derived from the specimens which were carried down

¹ *Sport and Travel*, by F. C. Selous, 1900, p. 156.

the streams during floods, and were buried in the estuarine deposits at the mouths of large rivers.

The creatures which inhabit the sea have a much better chance of being preserved as fossils, since deposits of one kind or another are constantly being formed over large areas of the sea-bottom, especially where subsidence is in progress. Yet even among marine forms of life there are many which would only rarely be entombed; those animals, for instance, which live on rocky shores and in clear water would not be preserved except where deposits of limestone were in process of formation. The majority of the creatures embedded would be those which lived on sandy and muddy bottoms, together with some of the free-swimming forms which moved through the water above.

Lastly, of the creatures so embedded only a small proportion would ultimately remain; those, namely, which possessed hard structures capable of fossilisation after the softer parts had decayed and disappeared. The following table shows at a glance which kinds of animals, out of all those which live in the sea, would be likely to leave memorials behind them and which would perish without leaving any trace of their existence.

Sub-kingdoms.	Groups with Hard Structures.	Perishable Groups.
Protozoa.	{ Foraminifera.	Flagellata.
	{ Radiolaria.	Infusoria.
Porifera.	{ Silicispongiæ.	Myxospongiæ.
	{ Calcispongiæ.	Ceratospongiæ.
	{ Sertularida.	Hydroida (except
	{ Hydrocorallina.	Sertularida).
Coelenterata.	{ Graptolitoida.	Siphonophora.
	{ Stromatoporoidea.	Discophora.
	{ Madreporaria.	Actiniaria.
	{ Some Alcyonaria.	Alcyonaria (some).
Echinoderma.	All classes.	Ctenophora.
Vermes.	{ Tubicola and the	None.
	{ jaws of Nereids.	horny { Hirudinea.
Arthropoda.	All classes.	{ Oligochaeta.
Molluscoida.	{ Bryozoa.	
	{ Brachiopoda.	
	{ Lamellibranchia.	
Mollusca.	{ Scaphopoda.	
	{ Gastropoda	except Nudibranchiata.
	{ Cephalopoda	except some Cuttle-fish.
Vertebrata.	{ Teeth, bones, and	
	{ scales of all kinds.	Tunicata.

But although all the classes of creatures entered in the second column possess hard parts which are capable of preservation, it does not follow that these are always preserved. Their conversion

into fossils depends partly on the solidity and character of the substance of which the hard parts are composed, and partly on the rapidity with which the remains are covered up and embedded in sediment. Lastly, their final preservation as fossils depends upon the conditions to which the embedding rock is subsequently exposed, upon its conservation or destruction.

The remains of those creatures which live in deep water or over deep water, such as many Foraminifera, Radiolaria, siliceous sponges, and pteropods, have such delicate tests and spicules that they often fall to pieces and become mere *debris* before they can be embedded in sediment; for in deep water the accumulation of sediment is usually a very slow process. The thin shells of the Radiolaria and the Pteropoda are especially liable to rapid disintegration, and consequently they are rare as fossils, although they are known to have existed from very early times.

2. *Subsequent Removal of Organic Remains.*—The proportion of those remains which would otherwise be preserved is further diminished by the subsequent destruction of some of them by the action of percolating water. All water which percolates downward from terrestrial surfaces contains carbonic acid, and such carbonated water attacks and dissolves carbonate of lime, and also that form of silica which enters into organic structures. Hence all such embedded remains are liable to solution and removal under certain circumstances.

So long as the deposit containing embedded organisms remains below the sea in which it was formed, it is probable that the changes which take place are slight and gradual. It is when the fossiliferous deposit is raised above the level of the sea and is added to the dry land that changes are apt to take place. Even then, if the rock has formed part of a thick series deposited during a long period of subsidence, and has remained buried beneath others for some time before the whole mass is raised to form land, most of the fossils in it are likely to be preserved, for the rock becomes consolidated and remains saturated with saline water, which probably contains as much carbonate of lime as it is capable of holding in solution under such conditions. Many fossils exhibit changes of structure which have very probably been effected during upheaval and while the rock was in a water-soaked condition; thus the substance of shells is frequently converted into crystalline calcite, and in other cases the calcareous shell is replaced by chalcedonic silica.

Those parts of a formation, however, which come to form the surface portions of newly raised land, *i.e.* those parts which are raised above the lowest summer level of saturation, are subjected

to the action of percolating water, with the result that many shells are dissolved, leaving only the hollows in which they lay. These hollow spaces may remain empty or they may be filled subsequently with infiltrated mineral matter, or if disturbances take place before the final consolidation of the rock, the internal cast may be squeezed on to the external impression of the shell and receive an impress of its ornamentation. In any of these cases some record of the original organism remains, but if the rock material is a loose sand or other very soft kind of sediment all trace of the organism may be destroyed.

With regard to the durability of the original shell much depends on its original mineral composition. In some shells and tests the carbonate of lime consists of the variety known as *calcite*, while in others it has the structure of *aragonite*, and it is a well-ascertained fact that *aragonite* is much less stable than *calcite*. It was pointed out by Mr. Sorby¹ that shells composed of *aragonite* disappeared much faster than the *calcite* shells when both were exposed to carbonated waters, and he pointed out that the creatures which possess hard calcareous structures can be separated into two sets according to the nature of the calcareous substance. These two sets may be tabulated as follows:—

Calcitic Structures.

Foraminifera.
Echinodermata.
Annelida.
Most Bryozoa.
Brachiopoda.
Oysters and Pectens.
Crustacea.

Aragonite Structures.

Calcareous sponges.
Actinozoa (corals, etc.).
Lamellibranchia (except Oysters,
Pectens, and the outer layer of
Spondylus, Pinna, and Mytilus).
Gastropoda (with a few exceptions).
Cephalopoda.

Professor P. F. Kendall has also made observations and experiments which confirm those of Mr. Sorby.² He has pointed out that in the Coralline Crag of Aldeburgh some fossils remain perfect, while of others there are only casts, and that the casts are without exception of *aragonite* shells, while the former are calcitic structures, such as Bryozoa, Echinoderms, Serpulæ, Brachiopoda, and the bivalve Molluscan genera, *Anomia*, *Ostrea*, *Pecten*, *Lima*, and *Pinna*; with the latter, however, occurred the Gastropod shell *Scalaria*, which he thought must be calcitic, an inference which subsequent experiment proved to be correct.

3. *Destruction of Fossiliferous Deposits.*—There is another set of agencies which contribute to render the geological record a very imperfect one. When any mass of marine deposit is raised into

¹ *Quart. Journ. Geol. Soc.* vol. xxxv. (1879), Pres. Address.

² *Geol. Mag.* 2nd Dec. vol. x. p. 497.

land, there is not only an absence of deposition, but there commences an actual destruction of the records previously accumulated. In the first place, as the rising deposit passes through the plane of the sea-level, it is exposed to the erosion of the waves, and if the latest deposits are not very thick, and the process of elevation is not very rapid, the probability is that only small portions will escape destruction. These portions will remain for a time as plains, marsh lands, and raised beaches; but as elevation continues, they will be brought gradually under the influence of atmospheric agencies, and exposed to continual wear and tear so long as they remain above the sea.

It follows, therefore, that only deposits of considerable thickness will survive the attacks of destructive agencies, and remain to form a permanent part of the earth's crust, but thick deposits cannot be accumulated in shallow seas, *which are the most favourable to life*, so long as the sea-bed remains stationary or is being elevated. Thick formations can only be accumulated in areas where constant subsidence has been in progress, or where the shore originally shelved rapidly into deep water, as off the coast of the Riviera. In the latter case the sediment will be rapidly accumulated, and will not contain so many or such varied forms of life; but under the former conditions, if the supply of sediment was sufficient to keep the sea shallow and to embed the organic remains, a formation rich in fossils, and thick enough, when upraised, to resist erosion, would be formed. We must, therefore, conclude with Darwin, "that nearly all our ancient formations, which are throughout the greater part of their thickness *rich in fossils*, have thus been formed during subsidence."¹

This conclusion that most of our great fossil-bearing formations have been deposited during subsidence has a very important bearing on the question before us, viz. whether the rocks are likely to contain the remains of an uninterrupted succession of species, or whether the record is more or less incomplete; for, as Darwin remarks:—

"During periods of elevation the area of the land and of the adjoining shoal parts of the sea will be increased, and new stations will often be formed—all circumstances favourable, as previously explained, for the formation of new varieties and species; but during such periods there will generally be a blank in the geological record. On the other hand, during subsidence the inhabited area and number of inhabitants will decrease (excepting on the shores of a continent when first broken up into an archipelago), and consequently during subsidence, though there will be much extinction, few new varieties or species will be formed;

¹ *Origin of Species*, sixth edition, p. 273.

and it is during these very periods of subsidence that the deposits which are richest in fossils have been accumulated.”¹

Succession of Faunas.—From the considerations above mentioned it will be seen that we cannot expect to find all the transitional forms which, if the theory of evolution be correct, must have connected one species with another, and have linked together all the past and present species of any one genus into one long chain of life. All that we can hope to find are certain cases where so large a number of closely allied species and varieties have been preserved as to furnish us with strong evidence of their having been links in such a chain.

There are, moreover, two well-established generalisations from palæontological facts which lead to a very significant inference; these considerations are (1) that the assemblage of fossils found in any formation has a general character intermediate between the assemblages above and below: and (2) that the fossils from two consecutive formations are far more closely related to each other than the fossils from two more remote formations. Commenting on these Darwin observes:² “On the theory of descent, the full meaning of the fossil remains from closely consecutive formations being closely related, though ranked as distinct species, is obvious. As the accumulation of each formation has often been interrupted, we ought not to expect to find in any one, or in any two, formations all the intermediate varieties between the species which appeared at the commencement and close of these periods; but we ought to find, after intervals very long as measured by years, but only moderately long as measured geologically, closely allied forms, or, as they have been called by some authors, representative species; and these assuredly we do find. We find, in short, such evidence of the slow and scarcely sensible mutations of specific forms as we have the right to expect.”

In spite, therefore, of the imperfection of the record, the known succession of life-forms does give very great support to the theory of evolution. Every succeeding fossil assemblage contains not only a larger number and greater variety of forms, but also some which are distinctly more specialised and more advanced in organisation. It is an acknowledged fact that many of the more ancient forms of life were what are termed “comprehensive types,” i.e. types which combine the structural characters of two or more different orders or classes of creatures, which are now completely differentiated from each other. In many cases also ancient animals resemble the embryos of the more recent animals belonging to the same classes.

¹ *Op. cit.* p. 275.

² *Op. cit.* sixth edition, p. 307.

Beyond all this there can be traced a distinct and decided progress in the types of life as we ascend the geological scale. It is true that in the earliest fauna yet known we start with a number of more or less specialised invertebrate types, but the more highly organised orders of Gastropods, Cephalopods, Crustacea, and Echinoderms do not appear till later periods; Fish are not known earlier than Silurian times; Amphibia commence in the Carboniferous; Reptiles in the Permian and Trias; Birds in the Jurassic; Mammals of low organisation in the Trias; higher Mammals, including Lemurs, appear in the Eocene, but true monkeys are not yet known from beds of greater age than the Miocene.

Zones.—It only remains to indicate how the succession of life-forms may be utilised for the purposes of subdivision and correlation, when we have to deal with a continuous succession of deposits, and more especially with a great thickness of one kind of deposit, such as shale or limestone. During the accumulation of such a mass of sediment it would seem that small changes were continually taking place in the *personnel* of the fauna, new forms taking the place of old ones, some species dying out and others coming in from elsewhere; so that when the fossils are carefully collected from each successive bed it is found that they form assemblages of species, each extending through a certain thickness of beds and thus characterising a band or zone within the formation.

A zone, therefore, is a certain thickness of stratified material which contains a certain assemblage of fossil species, some of these species being either restricted to the band or particularly abundant in it. Moreover, it is not merely a specially fossiliferous band in a thick mass of sediment, but is one of a succession of zones, each stage in a fossiliferous series being usually divisible into two, three, or more zones.

The following remarks on zones are quoted from the author's memoir on the Cretaceous Rocks of Britain.¹ "By the fauna of a zone we generally mean all the fossils which have been or can be found in the beds which are recognised as belonging to the zone. But what may be termed the critical fauna of a zone is the much smaller assemblage of fossils which are either restricted to it or are specially abundant in it. One of these species is then chosen as the index of the restricted assemblage of species, and the name of this fossil is given to the zone, so that we speak of it as the zone of this fossil, *e.g.* the zone of *Ammonites varians*, or the zone of *Belemnitella mucronata*.

"The reader must be cautioned against becoming possessed with

¹ "The Cretaceous Rocks of Britain," vol. i. p. 34, *Mem. Geol. Survey*.

the idea that a zone is a set of beds characterised by the occurrence of one particular species, and that every bed which yields this index-species must belong to the zone. It must be remembered that this particular species is only one of several or many, and that it is this assemblage of species which is the guide to the zone.

"The value and importance of a zone depends partly on the number of restricted species and partly on the extent of country over which it can be traced. The thickness of a zone is of course a stratigraphical accident, depending merely on the amount of sediment deposited at any locality during the lifetime of the zonal fauna. Thus a zone may be in one area only a few feet in thickness, in another it may be 20 or 30 feet, and in a third it may expand into 200 or 300 feet.

"The limits of a zone may be definite or indefinite. Where sedimentation has been continuous and fairly rapid, the limits of the zones will naturally be indefinite; some of the characteristic species of one zone may survive into the overlying zone, and others which are characteristic of the latter may make their first appearance in the former. Thus in many cases it is impossible to say exactly where the one zone ends and the other begins, and though by careful collecting one may fix it with fair certainty in one section, one cannot be certain of taking exactly the same plane of separation in another quarry or cliff which is a few miles away from the first. Thus where a zone is complete its limits are indefinite, but the succession of zones will be the same in both places.

"Where a zone has definite limits it is generally because sedimentation ceased for a time, and in many cases because an erosive current swept away some of the sediment which had previously been accumulated, thus destroying the continuity of the record and producing what is called a 'surface of contemporaneous erosion.' Even if the current was only strong enough to prevent the accumulation of sediment, it causes a break in the record, because for a time there is no embedment and preservation of organic remains. In this way, therefore, a zone or a sub-zone may die out when traced in a certain direction."

In some cases still smaller zonal subdivisions may be recognised, consisting of one or two beds which are characterised by one or more peculiar species; these may be called *sub-zones* or *hemerae*, but there is not necessarily a complete succession of such sub-zones, nor can they be expected to have so wide a geographical extension as zones; they are merely special horizons, and equivalent to the *niveaux* of French geologists.

Synchronism and Homotaxis.—It was stated in Chapter I. that when two districts are physically separated from one another

we have to rely entirely on community of fossils in comparing the rocks of the one with those of the other; and if the rocks so compared were deposited originally within the limits of the same life-province, the groups which contain similar assemblages of species may safely be regarded as contemporaneous.

To take an example, no one would hesitate to correlate the members of the Ordovician and Silurian Systems in North Wales and the Lake District by means of the fossils they contain, because there is every reason to suppose that the two districts formed part of the same province during those periods. Similarly the members of the Lower Cretaceous Series in the Isle of Wight and in the Weald may be correlated with some degree of exactitude; but the same group of beds in Lincolnshire contains such a different set of fossils that it obviously belonged to a different life-province, and it is impossible to indicate the exact equivalents of the several members of the southern series.

Again, when we come to compare districts at a still greater distance from one another—as, for instance, Wales and Bohemia, Sussex and the South of France, or England generally with North America—we find that there is certainly a general resemblance in the vertical succession of faunas which have flourished in the respective areas, *i.e.* the rock-series in each country can be divided into groups, which are characterised by the presence of the same genera; but the species are different, and it would be a mistake to conclude that portions of formations containing assemblages of the same genera in countries so far apart were contemporaneous in the same sense as the members of the Silurian Series in Wales and Cumberland are contemporaneous.

A group of species originating in one locality and spreading along the coasts of a continent would take a long time to travel from Europe to America even if there were continuous coast lines. Sometimes their progress would be arrested for a time, until physical or geographical changes allowed them to advance; at other times they would make their way by accommodating themselves to varying conditions and by throwing out collateral varieties. The date of their first appearance in one part of the world would be very much in advance of their arrival in the other, so that the fact of two distant formations containing fossils of closely allied species can be no proof of their being really contemporaneous.

It is certain, however, that in every part of the world the geological sequence discloses the same general succession of life-forms. The progress of development may have been retarded here and accelerated there, but the successive fossil assemblages are similar to one another, and the order in which they occur is the

same all over the world. We never find a Carboniferous fauna antedating a Silurian or Devonian fauna, though we may find the first succeeding the second without the presence of the intermediate Devonian assemblage. This common order of succession has been termed *Homotaxis*, and the Silurian System of Britain is spoken of as *homotaxial* with and equivalent to the Silurian of America; even the larger subdivisions of the one may be paralleled with those of the other, as homotaxial equivalents or representatives, so that we may speak of the Niagara Group as equivalent to the Wenlock Beds, understanding by this that the groups are homotaxial equivalents and not absolutely coeval formations.

To sum up the preceding observations, the occurrence of the same assemblage of species at different localities may be taken as evidence that the beds containing them are of the same age, and were formed at the same time. Again, a knowledge of the general succession of generic forms enables us to fix the relative age of any set of fossils, and, consequently, the homotaxial position of the beds containing them. In other words:

1. Assemblages having many species in common may be regarded as contemporaneous.
2. Assemblages having many genera in common may be regarded as homotaxial equivalents.

CHAPTER III

THE LITERATURE OF HISTORICAL GEOLOGY

It is believed that some information as to the principal geological publications and as to the facilities for ascertaining what has been published about any particular system or series of beds would be useful to the student.

During the first half of the last century, and indeed up to about the year 1860, publications on stratigraphical geology were comparatively few, and it was possible for any geologist to have a fair acquaintance with all that had been written on the subject; but as time went on the number of workers increased, and more numerous additions were made every year to our knowledge of British rocks and fossils, as well as of their equivalents in other countries.

Every year added a volume to the publications of the Geological Societies of London, Edinburgh, Glasgow, Manchester, and other centres, to the volumes of the Palæontographical Society and of the *Geological Magazine*. The Geological Survey also have issued a long succession of maps and memoirs, most of which have appeared within the last forty years.

At the present day, therefore, it is almost impossible for any one to make himself acquainted with all that has been written on the stratified rocks of Great Britain, and quite impossible to have at the same time a good knowledge of the fossils which they contain. Consequently in these branches of geology, as in the case of other sciences, the tendency is toward the specialising of knowledge. After the student has acquired a certain amount of knowledge about the successive geological systems and their characteristic fossils he probably becomes specially interested in one of them, or in the rocks which occur in some particular district, and then he wishes to know in what books and memoirs accounts of that series of rocks or of that particular district have appeared.

The descriptive parts of this volume contain only the more

important facts respecting each system of rocks. The book is designed to include only so much information about each great series of stratified deposits as the student may be expected to read and to have before him for constant reference. Descriptions of each successive series will be given with a certain amount of detail concerning the variations which they exhibit in the British Islands, and their representatives on the European continent will be indicated in a more concise manner, but yet in sufficient detail to give the student some idea of their known extent and of the conditions under which they were deposited.

But the task of selecting information from the great mass of detail which has now been accumulated is not an easy one, and further, what is regarded as specially important in one part of the country may seem of less importance in another part, for naturally each teacher will wish his pupils to become specially acquainted with the rocks of the country or district in which they live. I propose, therefore, in this chapter to indicate briefly what are the most important and useful publications, how they can be obtained, and how they should be used, in order that the reader may learn how to extend his knowledge of any particular series of rocks, or to find out what has been published about the geology of any special district.

The publications may be grouped under four heads—Maps, Stratigraphy, Palæontology, Palæogeography.

MAPS

It is necessary that the student should have access to a geological map of the British Islands. Every teacher will doubtless see the necessity of exhibiting one in his lecture-room, but every student should as soon as possible acquire one for himself. Fortunately a good cheap map of the British Isles is no longer a desideratum, for one is now issued by the Geological Survey at the low price of 2s. There are several others on a larger scale at a higher price, as well as good separate maps of England, Scotland, and Ireland.

The following general maps may be recommended :—

1. *Geological Survey Index Map*. Scale 25 miles to an inch, 2s.
2. *Geological Map of the British Isles*, from Stanford's London Atlas. Price as separate map, 10s. 6d.
3. *Stanford's Geological Atlas of Great Britain and Ireland*, edited by H. B. Woodward, 2nd edition enlarged, with plates of characteristic fossils. Price 12s. 6d. net.

4. *Geological Map of England and Wales*, by Woodward and Goodchild, $17\frac{1}{2}$ miles to an inch. Price 5s., in case 7s. 6d.
5. *Geological Map of England and Wales*, by Sir A. Geikie. Scale 10 miles to an inch. Price 10s.
6. *Geological Map of Scotland*, by Sir A. Geikie (Bartholomew). Scale 10 miles to an inch. Price 6s.
7. *Map of the Surface Geology of Ireland*, by Sir A. Geikie (1908). Scale 10 miles to an inch. Price 4s. 6d.
8. *Geological Map of Western and Central Europe*, reduced from the International map. Stanford. (In preparation.)

Besides the small index map above mentioned the Geological Survey publishes a larger Index Map on the scale of 4 miles to an inch, a new edition of which is in course of publication in 19 sheets, most of which are issued and priced from 2s. to 2s. 6d.

If maps of a special district are required the reader should write for a catalogue of the maps issued by the Geological Survey of the United Kingdom, this catalogue being obtainable from Mr. E. Stanford, Long Acre, London; or from W. and A. K. Johnston, Edinburgh, or from Hodges, Figgis, and Co., Dublin.

Besides the index map above mentioned the Geological Survey issues two sets of maps on the scale of one inch to a mile, one being known as the "Old Series," the other as the "New Series."

STRATIGRAPHY

It will be convenient to mention first those books and memoirs which are of a general nature but yet give more information about certain formations than will be found in this volume.

The most complete Manual of Geology in English is Sir A. Geikie's *Text-book of Geology*, 4th edition (1903) published by Macmillan and Co. in 2 volumes, price 32s.. The second volume deals with Stratigraphical Geology and includes accounts of the foreign equivalents of each system, not only in Europe but in other parts of the world. A similar work in French is De Lapparent's *Traité de Géologie*, 5th edition (1905), in 3 volumes, price 35s.

A useful epitomé of the geology of many counties and districts in England and Wales will be found in the Jubilee volume issued by the Geologists' Association in four parts, price 5s. each (1910). Each article in this publication has been written by a geologist who is specially well acquainted with the district he describes.

The Geological Survey has published the following memoirs, which deal either with special formations or with districts of considerable size and importance:—

- The Geology of North Wales*, by Sir A. Ramsay, 2nd edition (1881). Price 21s. with map and sections.
- The Geology of the N. W. Highlands of Scotland*, by B. N. Peach, J. Horne, and others (1907). Price 10s. 6d.
- The Geology of the Southern Uplands of Scotland*, by B. N. Peach, J. Horne, and others (1900). Price 15s.
- The Geology of London and of Part of the Thames Valley*, by W. Whitaker, in two volumes (1889). Price 11s.
- Guide to the Geology of London and the Neighbourhood*, by W. Whitaker and H. B. Woodward. Price 1s.
- The Geology of the Bristol and Somerset Coal-field*, by H. B. Woodward (1876). Price 18s.
- The Triassic and Permian Rocks of the Midland Counties of England*, by E. Hull (1869). Price 5s.
- The Geology of the Weald*, by W. Topley (1875). Price 17s. 6d.
- The Geology of the Isle of Wight*, by C. Reid and A. Strahan (1889). Price 8s. 6d.
- The Geology of the Isle of Purbeck and Weymouth*, by A. Strahan (1898). Price 10s. 6d.
- The Jurassic Rocks of Britain—*
- Vol. I. Yorkshire, by C. Fox-Strangways (1892). Price 8s. 6d.
- Vol. II. Yorkshire, by C. Fox-Strangways. Tables of Fossils. Price 12s.
- Vol. III. The Lias of England and Wales, by H. B. Woodward (1893). Price 7s. 6d.
- Vol. IV. The Lower Oolitic Rocks of England, by H. B. Woodward (1894). Price 10s.
- Vol. V. The Middle and Upper Oolitic Rocks of England, by H. B. Woodward (1895), with Bibliography of Jurassic Literature. Price 7s. 6d.
- The Cretaceous Rocks of Britain—*
- Vol. I. The Gault and Upper Greensand, by A. J. Jukes-Browne (1900). Price 9s.
- Vol. II. The Lower and Middle Chalk of England, by A. J. Jukes-Browne and W. Hill (1903). Price 10s.
- Vol. III. The Upper Chalk of England, by A. J. Jukes-Browne and W. Hill (1904). Price 10s.
- The Pliocene Deposits of Britain*, by C. Reid (1890). Price 5s. 6d.

A list of the smaller or more local memoirs (explanations of various sheets of the one-inch map) will be found in the Catalogue

of Maps and Memoirs issued by the Survey. Many of them have lists of the publications referring to the district under description.

The next most important source of information is the *Quarterly Journal of the Geological Society of London*, the publication of which commenced in 1845. There is an excellent index to the first fifty volumes of this Journal, which can be purchased from the Geological Society, Burlington House, London (price 10s.). This index gives references to the names of authors, of places, and of subjects, so that by its means it is easy to ascertain what papers have been published in the Journal on any particular area or any set of beds. This index deals with the yearly volumes between 1845 and 1894.

The Geological Society also publishes every year a list of the various items of geological literature which have been added to its library. This publication began in 1894, with a list for the latter half of that year (price 1s.). Each succeeding annual part is issued in a paper cover (price 2s.), and is divided into two portions, the first being an index of authors' names with titles of papers, and the second an index of subjects, and each separate paper in all the publications purchased or received by the Geological Society is entered in these indices, as well as all the papers published in the *Quarterly Journal* of the Society since 1894. It will be seen, therefore, that this annual list forms a fairly good index to the geological literature of the whole world.

Before this work was taken in hand by the Geological Society of London two attempts had been made in England to establish an annual record of geological literature. These were :—

1. The *Geological Record*, consisting of six annual volumes (1874-1879), edited by W. Whitaker, giving short abstracts of all papers, British and foreign; and two volumes (for 1880 to 1884 inclusive), edited by W. Topley, giving titles only. Published by Taylor and Francis, London. Price 16s. per volume.
2. The *Annals of British Geology*, by J. F. Blake (Dulau and Co., London). Four volumes (1890-1893). Price of the vol. for 1890, 5s., of others, 9s.

The volumes of the *Geological Magazine* contain many articles on stratigraphical geology, and a general Index to all the volumes from 1864 to 1903 has been published, price 21s.

The Geologists' Association publishes *Proceedings* which contain many useful papers, and each volume contains the proceedings and communications of two years, with accounts of excursions and a good index. The first volume is for the years 1868-69.

Of the provincial societies which publish geological papers the

chief are the following:—the Geological Societies of Edinburgh, Glasgow, Manchester, and Liverpool, the Yorkshire Geological and Polytechnic Society, and the Royal Geological Society of Cornwall.

Particulars respecting the above and all other scientific societies in the United Kingdom will be found in the *Official Year-Book of Scientific and Learned Societies*, published by C. Griffin and Co., Strand, London. Price 7s. 6d. each annual volume.

The British Islands have been the scene of repeated volcanic eruptions, and volcanic products are interbedded with the sediments of all the Palæozoic systems, except perhaps the Permian. Brief descriptions of the contemporaneous volcanic rocks will be given in the following pages after that of the sedimentary rocks of each period, but the reader will find this part of the subject admirably treated by Sir Archibald Geikie in his *Ancient Volcanoes of Great Britain* (Macmillan and Co., 2 vols. 1897, price 36s.).

PALÆONTOLOGY

For the proper study of historical geology it is essential that the student should have some knowledge of the forms and structure of the different classes of animals, and especially of the Invertebrate classes. This general acquaintance he can get from a careful perusal of Mr. H. Woods's small manual of Palæontology in the Cambridge Natural Science Series (second edition, 1899, price 6s.), but he may sometimes find it necessary to refer to larger books on the subject. Of these the best are:—

A Manual of Palæontology, by Messrs. Nicholson and Lydekker, third edition, in two volumes (1889), price 42s.

Zittel's *Text-book of Palæontology*, the American edition of 1900, published by Macmillan and Co., vol. i., price 25s.

Outlines of Vertebrate Palæontology, by A. S. Woodward, Camb. Univ. Press, price 14s.

Besides these may be mentioned a series of volumes now being issued under the title of *A Treatise on Zoology*, edited by Professor E. R. Lankester, and published by A. and C. Black. This series will be complete in ten parts, of which nine have been published. Price from 12s. 6d. to 15s. per part. Fossil forms are dealt with in most of them.

The stratigraphical geologist, however, has to deal with fossils principally as important aids in determining the relative age of rocks, and he has therefore to make himself acquainted with the fossils which are most characteristic of the different systems, and especially with those species which have a restricted range within each system and thus characterise stages and zones.

Lists of characteristic fossils will be given in this volume, together with figures of some of them. The student will, however, be glad to know where he may find figures of other species, and he may consult the following books with advantage :—

For Palæozoic fossils a useful book is Baily's *Characteristic British Fossils*, vol. i. (Palæozoic), with 42 plates (1875). Copies of this can still be obtained from Messrs. Dulau and Co., 37 Soho Square, London. Price 10s.

For Tertiary fossils Lowry's *Chart of Characteristic Tertiary Fossils* can be recommended. (Stanford. Price 4s.)

For fossil Crustacea Woodward and Lowry's *Chart of Fossil Crustacea* is good, though not limited to British species.

The more recent memoirs of the Geological Survey—that is to say most of those published since 1890—contain figures of some of the characteristic fossils of the formations described. The memoirs on the Jurassic rocks and on the Cretaceous rocks may be specially mentioned as containing many figures of fossils that will be useful to the student.

For illustrations of fossil plants and for information on their structure Seward's *Fossil Plants* should be consulted (Cambridge Nat. Science Manuals, two volumes, price 12s. each). *Studies in Fossil Botany*, by D. H. Scott (A. and C. Black), is also excellent.

As works of reference which ought to be found in every library of scientific books the publications of the Palæontographical Society must be mentioned, for these volumes are the great storehouse of illustrations of British fossils. The annual quarto volume of the Society costs only 21s., and contains parts of four or five monographs, with from thirty to forty plates. The Society was established in 1847, and a list of the monographs which have been completed and of those which are in progress can be obtained from Messrs. Dulau and Co. (Soho Square, London). The completed monographs can be purchased separately, and include monographs on Fossil Corals, Echinoderms, Brachiopoda, Trilobites, Devonian Fossils, Mollusca of the Crag, Cretaceous Bivalves, and Ammonites of the Lias.

Another work of reference is Etheridge's *Fossils of the British Isles*, vol. i. (Clarendon Press, Oxford, 1888), which is a complete list of the fossils recorded from the Palæozoic rocks of Britain up to that year, showing the range of each species.

PALÆOGEOGRAPHY

The geography of the earth's surface has gone through a long series of phases and mutations. Each period may be said to have

had a geography of its own, but the special phase with which it opened slowly changed toward the evolution of the ensuing phase by the upheaval of one region and the subsidence of others, or by a general regional movement of elevation or subsidence. Sometimes indeed great changes seem to have taken place within the duration of a single period. The present arrangement of land and sea, as well as their relative heights and depths, is merely the last of these phases, but it is at the same time a result of the geographical evolution which has been in progress ever since the earth's crust was cool enough for water to condense and settle upon it; in other words, modern geography is the outcome of all the past geographical changes.

The restoration of ancient phases of geography, the attempt to indicate the limits of the seas and the positions of the land areas of any age or period, is one of the most difficult problems that a geologist can endeavour to solve. Shore-lines are seldom preserved, and the essay involves a careful consideration of the conditions under which various local deposits have been formed, and a studied use of the scientific imagination in estimating the original extension of deposits, of which only small portions are in many cases preserved or exposed.

Such endeavours to restore the geographical conditions of past periods must at present be tentative, and with respect to the older periods they are probably more suggestive than real; but they exercise the faculty of inductive reasoning, and they help to show the student that there are aims and objects to be attained by the study of historical geology which are more interesting than the mere enumeration of rock-groups or the recognition of characteristic fossils.

A brief account of the conditions under which each series of rocks has been accumulated and of the relative positions of land and sea in the European region during each period will be given in the following pages; but for more detailed consideration of the geographical changes in the British area the reader is referred to the author's treatise on the *Building of the British Isles* (third edition, 1911, Stanford), and to Professor Hull's *Contributions to the Physical History of the British Isles* (1882, Stanford). He will also find maps that deal with a wider area in the last edition (fifth) of De Lapparent's *Traité de Géologie* (1905).

CHAPTER IV

THE ARCHÆAN ROCKS

A. CLASSIFICATION AND NOMENCLATURE

IN this chapter we shall deal with the oldest rocks which are known to enter into the surface-structure of the earth's crust, rocks which can be seen to emerge from below the oldest fossiliferous (Cambrian) strata, not only in Britain but in many other parts of the world.

These primitive formations consist mainly of crystalline rocks—granite, gneiss, and crystalline schists—but they also include great thicknesses of stratified rocks, partly sedimentary and partly volcanic, which have not been altered beyond recognition as such rocks. Gneisses and crystalline schists belong to a category of their own and are generally termed metamorphic rocks, yet they have certainly not all been formed in the same way, and the determination of their relative age and manner of formation is often a very difficult matter. Even the stratified Archæan rocks cannot be classified and correlated in the same way as those of the Palæozoic systems can, because they are destitute of fossils, except some minute microscopic bodies, and because they vary greatly in lithological composition and in the extent of metamorphic change which they have undergone.

Consequently, when a succession of pre-Cambrian rocks has been made out in any one area, it is very difficult to correlate the divisions which are observable in this area with those which can be made out in another. Even with regard to larger divisions, of the rank of series or systems, European geologists have not yet formulated any classification which has met with general acceptance. They differ as to the number of rock-groups which can be recognised in some of the principal areas of pre-Cambrian rocks, and also as to the relative age of some of the component rock-masses; and in some cases it is a matter of dispute whether certain schists and

phyllites are of Archæan age at all, or are metamorphosed sediments of much later date.

All agree, however, in admitting that in the regions where large tracts of pre-Cambrian rocks are exposed, there is a general succession from an older to a younger series, and that in some areas there is a distinct break and unconformity between the older and younger series. Thus there is no doubt that the Archæan rocks can be divided into two distinct systems, and some continental geologists advocate the restriction of the name Archæan to the older series and apply that of pre-Cambrian to the newer and more distinctly stratified series. This, however, is not a satisfactory nomenclature, for the term pre-Cambrian is an indefinite and inconvenient name for a system or a period, though it is a useful adjective in a general sense. It is better, therefore, to call all pre-Cambrian rocks *Archæan*, using the term *Protarchæan* for the oldest and *Nearchæan* or *Eparchæan* for the younger series.

Difficulties, however, still remain, because in some countries, and notably in America, the older crystalline rocks have been divided into two and even three series, while in some areas two series of distinctly stratified rocks are believed to exist. Ultimately it may be possible to divide the whole into three distinct systems, as suggested by Professor Bonney, which may then be called *Protarchæan*, *Mesarchæan*, and *Eparchæan*.^{1 a}

Meanwhile at the present time the rock-groups which have been recognised in different areas are known by different local names; so that not only every country, but almost every separate district in which Archæan rocks are exposed, has its own special nomenclature, and it is seldom possible to correlate the groups established in one country with those of another.

Under these circumstances it is obvious that the Archæan rocks cannot be described in separate chapters on a stratigraphical basis, but must be dealt with regionally, those of each large area being described separately and successively. As regards their total thickness exaggerated ideas seem to prevail in some quarters. Attempts to estimate the thickness of crystalline schists are quite untrustworthy, and where that of the stratified series can be estimated their thickness is not more than that attained by Cambrian or Silurian strata in some districts, i.e. from 10,000 to 16,000 feet.

^a References will be found at the end of the chapter.

B. BRITISH REPRESENTATIVES

1. *Scotland*

By looking at any geological map of Scotland the reader will see that, if the Outer Hebrides are included, about two-thirds of the whole country are occupied by gneissic, schistose, and semi-crystalline rocks, which are believed to be older than the Cambrian. There is now no doubt that this great region of the Scottish Highlands includes several series of pre-Cambrian rocks, and the region is divisible into three areas: (1) a western area, including the Hebrides, the western parts of Sutherland and Ross, and tracts in Skye, Mull, and Islay; (2) a broad medial area extending from the north coast of Sutherland to the south of Inverness; (3) the Central Highlands from Aberdeen to Argyllshire.

Parts of these three areas are shown on the accompanying map (Fig. 1), and they appear to include three different series of Archæan rocks, though each area contains representatives of more than one division, and it is only in the west that the relative positions of two of these divisions are quite clear.

The western belt is marked off from the median tract by a thrust-plane of enormous displacement which is known as the Moine thrust. The western outcrop of this plane runs from Whiten Head near Loch Eriboll in a S.S.W. direction, through Sutherland and Ross and through the Sound of Sleat. Thence it probably passes outside the Isles of Mull and Islay. West of this line the Archæan rocks are comparatively unaltered and seem, indeed, to have undergone little change from the condition in which they existed when the early Cambrian sandstones were deposited, while the areas to the east of them have been subjected to enormous pressures, with resulting dynamic metamorphism produced at some post-Cambrian date.

The north-west area in Sutherland and Ross has long been known for its clear presentation of three distinct rock-systems, though the precise ages of these three systems was for a long time in doubt. Each is separated from that below by a great unconformity, and the highest of them is now known to be Cambrian. The other two have been named the Torridonian or Torridon sandstone, and lowest of all the Hebridean or Lewisian gneiss.

The following description of the Hebridean gneiss is taken from the Report of the geological mapping of the area, published in 1888.² In the cliffs between Cape Wrath and Loch Torridon they present two types of structure, appearing in some parts as "massive rudely foliated crystalline rocks, with few divisional planes, or [in other

parts] as well-banded gneisses in which the constituents have a distinct parallel arrangement. Both varieties are traversed by segregation veins and pegmatites. The prominent minerals are plagioclase felspar, pyroxene (augite), hornblende, quartz (frequently opalescent), and magnetite. It is worthy of note that mica is a rare constituent of these original types of gneiss. On close examination it is apparent that the bands present certain lithological varieties of variable thickness; some consisting mainly of pyroxene or hornblende and a small quantity of plagioclase felspar; some of plagioclase, pyroxene or hornblende, and opalescent quartz; others of opalescent quartz and felspar. These varieties frequently cross the lines of schistosity, and are evidently due to differences in the nature of the materials prior to the development of the foliation."

In some places these foliated rocks include masses of non-foliated basic igneous rock (gabbros, peridotites, augite-granulites, and diorites), arranged in lenticular belts which are more or less parallel to the foliation. These patches and belts are intersected by veins of grey pegmatite, consisting mainly of felspar and quartz, and varying in thickness from a few inches to several yards. But when these non-foliated masses are carefully traced it is found that they pass laterally into the rudely foliated basic gneisses and that the pegmatites merge into quartz-felspar schists. Hence it is concluded that almost the entire mass consisted originally of igneous rocks, and that the gneisses have been developed by deformation alone; but that there was an original differentiation of the felspathic and hornblendic elements, either by separate intrusion or by fluxion, while the rocks were still in a viscous condition. There is no doubt, however, that the members of the original complex must have been subsequently affected by intense pressure inducing plastic deformation and metamorphism.

The gneisses are also traversed by other dykes of basic igneous rock—diabase, epidiorite, and picrite—but these are nevertheless of a date anterior to that of the overlying Torridon sandstone which they do not enter. Most of these dykes run from S.E. to N.W. or W.N.W. Moreover, detailed mapping of the area has shown that after the intrusion of the igneous dykes, and still before the deposition of the Torridonian, the whole region was subjected to intense lateral pressure which caused much plication of the gneisses and produced bands of disruption or "shear-zones" which run approximately east and west.

In certain parts of the area, *i.e.* near Gairloch and Loch Maree, rocks of a different character make their appearance and seem to lie within a broad and deep synclinal fold of the Hebridean gneiss.³ They consist of schists which are clearly altered sediments, but their

relation to the gneiss is uncertain because the planes of contact seem to be shear-planes with bands of crushed rock, but they are clearly older than the Torridon sandstone.

This schistose series consists for the most part of mica-schist, graphite-schist, and crystalline limestone, with bands that may represent altered quartzite and chert; and there are also broad outcrops of hornblende-schist which are probably dykes or sills of basic igneous rock. There are several bands of limestone, varying in thickness from 3 to 30 feet; one of the best known is the Letterewe limestone, which is a cream-coloured rock containing lumps of actinolite; it was formerly extensively quarried. Another band at Ardlair is a white saccharoid dolomite.

The existence of this tract of metamorphosed sediments to the west of the great thrust-plane is important, because it may be regarded as a remnant of a mass of such rocks which was originally much more extensive, and seems to occupy an intermediate position between the Hebridean gneiss and the Torridon sandstone. We shall presently see that the more highly metamorphosed complex of rocks to the eastward includes representatives of a similar schistose series, and it has been reasonably supposed that the Loch Maree Series represents some of the sedimentary rocks into which the Hebridean gneisses were intruded.

Hebridean gneisses are found on the western border of Inverness, opposite Skye, and in the peninsula of Sleat; they form the islands of Coll and Tiree and occur in Iona and Soa; they are also exposed in the north-east part of Colonsay and again in the south-western part of Islay which terminates in the precipices of Rhinns Point. The gneisses of Islay are similar to those of the north-west, but Dr. Teall observes⁴ that under the microscope they show evidence of profound modification by pressure, "the general result of which has been to crush the original constituents and thus to produce microscopic breccias, not holocrystalline schists."

The features of the belt of faulted and overthrust masses of rock which separates the western and eastern areas of the Northern Highlands are sufficiently illustrated in Figs. 2 and 3, drawn by the Officers of the Geological Survey, and the details of its structure need not be described in this place. It is only necessary to note that the rocks which occupy the country to the east of the great Moine thrust have been so crushed, crumpled, and metamorphosed that they now have special aspects of their own.

Part of the great median area of schistose rocks is shown on the map (Fig. 1); it comprises the greater parts of Sutherland, Ross, Cromarty, and Inverness; it extends across the "great glen" into Nairn and Elgin, and southwards through the Forest of Athol

Fig. 2.—SECTION FROM QUINAG, ABOVE LOCH ASSYNT, TO BEN UIDHE.
(Distance about 6 miles.)

Fig. 3.—SECTION FROM KNOCHAN CLIFF, NEAR ELPHIN, THROUGH THE CROMALT HILLS.
(Distance about 6 miles.)

{ 7. Durness limestone.
6. Serpulite grit.
5. Fucoid Beds.
4. Upper quartzite.
3. Lower quartzite.
Cambrian.

S. Lands compounded of 5, 6,
and 7, repeated by minor
thrusts.
t & T. Thrust-planes.
T₁, T₂, T₃. Major thrust-planes.

2. Torridon sandstone.
1. Hebridean gneiss.
10. In Fig. 3, Overthrust Moine schists
resting on the plane of the Moine
thrust (T₃).

Both these sections are reproduced by permission from *Quart. Journ. Geol. Soc.* vol. xlv. p. 418 *et seq.*

to and beyond Loch Rannoch, as well as to the eastern end of Loch Leven, but south of this line it becomes infolded with the Grampian Series.

The whole of this area has now been surveyed by the staff of the Geological Survey of Scotland, and some important conclusions have been reached. These have been cautiously announced from time to time in the annual "Summaries of Progress," from which extracts and abstracts will here be given.

In 1904 and 1905 it was found that over a large area embracing parts of Ross, Inverness, and Nairn the metamorphosed rocks could be separated into two divisions: (1) a complex group consisting partly of gneisses of Hebridean type and partly of altered sedimentary rocks; (2) certain gneissic schists of both siliceous and pelitic types which, being intimately connected, were termed the Moine schists. Further, the mapping of these areas showed that the Hebridean gneisses occurred as inliers surrounded by Moine schists, and that the latter appeared to lie unconformably on all the members of group 1; the lowest part of the granulitic schists being a band containing fragments of felspathic gneiss and having all the aspect of a sheared conglomerate.

These conclusions have been confirmed by subsequent work, and the altered sediments in the Hebridean complex are found to include crystalline marbles, calcareous silicates, and brown mica-schists which are often graphitic, associated with banded hornblendic gneisses. The reader will perceive that there is a striking resemblance between this series and that of the Loch Maree Beds above described. Dr. Flett, writing in 1905, says "such rocks are a characteristic part of the Lewisian in certain areas" (*i.e.* Glenelg and Loch Maree) and remarks that they differ widely from any of the Moine Schist Series. It is evident that two sedimentary series are present in the Moine schist area, the one associated with the Hebridean, and of considerable thickness, but largely eroded and removed before the deposition of the other (*i.e.* the Moine schists).

The Moine schists present two different types of rock which can be separately mapped; these are (1) psammitic schists or flaggy granulites composed of quartz, felspar, and biotite, (2) pelitic or argillaceous schists now converted into mica-schists in which white muscovite mica predominates. The mapping of Ross and Inverness has led to the belief that these are not merely successive but that there are two bands of psammitic and two of pelitic schists; there are also occasional seams of quartz-schist and of calcareous schist. The whole mass of the Moine schists has apparently been formed out of a series of sandstones and sandy shales.

Proof of the last statement has recently been obtained by Messrs.

Clough and Crampton⁵ from a study of the aureole or zone of contact-metamorphism round the gneissic granite of Carn Chuineag in Ross-shire. Within this zone the Moine sediment was altered and indurated before the incidence of the dynamic metamorphism, the consequence being that the beds have to a large extent escaped the effects of that metamorphism and can be recognised as hornfelses formed from the alteration of ordinary sandstone and shales.

The hornfelses occur where a sandy shale was in contact with the granite; it is now a hard and splintery rock, and where least affected by subsequent shearing it shows both a clastic structure and the original lamination. The more quartzose bands often contain minute pebbles of rounded quartz; and "On the surfaces of certain layers there are markings strongly suggestive of sun-cracks and ripple-marks, and others which may possibly represent worm-tubes." Moreover, the beds lie with gentle inclinations, and they dip at right angles to the general direction of the foliation-bedding or shearing of the neighbouring schists. Lastly, intermediate stages between the typical hornfels and the foliated schists have been observed; and it is clear that all the rocks were solid at the time when the pressure-foliation was induced, the granite being then converted into a gneiss and the shales into mica-schists, while the rocks of the indurated aureole were more resistant and are consequently much less altered.

The Moine schists and the underlying Hebridean rocks have now a common foliation which has obscured that which previously existed in the older series: they have also a common flexion and plication, the rock-masses being folded into a complex system of isoclinal, the prevalent strike of which is from S.S.W. to N.N.E., though they vary in direction round the inliers of Hebridean gneiss.

The above description applies more particularly to the areas north and west of the Great Caledonian Glen. East of the faults which run along this glen the country is occupied by large tracts of similar quartzo-felspathic schists, which, however, differ in being more persistently flaggy, the layers being alternately more and less micaceous. Hence the name *Eilde Flags* has recently been used as a special designation of this portion or facies of the Moine schists.⁶

We now pass to the equally large area of the Central Highlands, which extends across the centre of Scotland from parts of Aberdeen and Kincardine on the N.E. through Perthshire and Argyllshire to the coasts of Cantire and Islay. This area is occupied mainly by three different kinds of rocks, first and principally by a series of metamorphosed sediments comprising quartzites, phyllites, and limestones, secondly of *small* tracts of *Eilde flags*, and thirdly of

large intrusive masses or bosses of granite. The stratified series has been called the *Grampian Series* by Dr. Hicks⁷ (1883) and the *Dalradian* by Sir A. Geikie⁸ (1891).

The mapping of this extensive area by the Geological Survey has been in progress for many years, and reports on successive portions have been published in the annual "Summaries of Progress." From these we learn that the successive belts of altered stratified rocks are not difficult to follow, but that, owing to the isoclinal folding and the intense plication, it is not easy to unravel the true succession from oldest to newest. In Argyllshire, however, where the metamorphism is less and the physical structure less complicated, the succession appears to be as follows, according to E. B. Bailey,⁶ though it is not yet known whether it should be read upwards or downwards.

9. Eilde flags.
8. Glen Coe quartzite (white and fine-grained).
7. Leven schists, grey phyllites, and others with quartzite bands.
6. Ballachulish limestone and black slates (= Easdale slates).
5. Striped Transition Series (not always present).
4. Appin and Loch Awe quartzite (a pebbly rock).
3. Appin limestone (cream coloured).
2. Appin phyllites, with bands of flaggy quartzite.
1. Cuil Bay slates (black).

The section (Fig. 4) represents Mr. Bailey's theory of the arrangement of these groups in a series of recumbent folds, and from it the reader will understand the difficulty of ascertaining the real order of succession.

With regard to the total thickness of these groups no exact measurements have been made, but Mr. Bailey states that "even the thinnest of them, the Appin limestone, is probably not less than 100 feet thick, while the Leven schists, Glen Coe quartzite, and Eilde flags must each of them reach about 1000 feet; the other members of the sequence should doubtless be reckoned in hundreds of feet. These rough estimates refer to original thickness of deposition. Now over wide areas various groups are reduced to mere films, . . . elsewhere again their dimensions have been mightily increased by reduplication." We may infer, therefore, that the whole series, exclusive of the Eilde flags, must have been originally between 4000 and 5000 feet thick at least.

The Appin quartzite is specially interesting because what may be its base is generally a pebble-bed or conglomerate; moreover, the Appin limestone sometimes passes through a pebbly calcareous rock into the quartzite, so that the evidence of superposition is doubtful. The pebbles are chiefly of quartz and pink felspar. In other parts of the Highlands what seems to be the same quartzite

has a border or base containing stones of the size of boulders as well as pebbles.

The above may be an ascending or descending sequence. Hitherto it has been generally supposed that the rocks of the Central Highlands are younger than those to the north-west of them, but this is an assumption, and the intermediate position of the Moine schists between the unaltered Hebridean area and the Grampian range may be merely a geographical and structural accident. It does not follow that they are of intermediate age, and we shall see in the sequel that the general order of succession in the metamorphic area may have to be read from south-east to north-west.

We must now return to the north-western area and give some

FIG. 4.—SECTION FROM LOCH LINNHE TO LOCH ETIVE.

Copied from Mr. Bailey. Distance about 14 miles.

The numbers refer to those in the succession given on p. 43.

account of the Torridon sandstone, which in that area is the only formation occupying an intermediate position between the Hebridean complex and the Cambrian quartzites. There is, however, a remarkable gap and unconformity between the gneisses and the Torridon sandstones, and this gap must represent a long interval of time. In some places the surface of the gneiss is a gently undulating plain, but elsewhere it had been carved into a series of hills and valleys, the former rising to heights of from a few hundred to more than 2000 feet above the valley-bottoms.⁹

Moreover, the basement beds of the Torridonian are generally in the form of a conglomerate or breccia, the components of which have been mainly derived from the underlying gneisses, but except in this conglomerate fragments of gneiss are by no means abundant in the overlying coarse sandstones, and most of the pebbles found in them consist of rocks which differ from any now exposed in Sutherland or Ross. They include many kinds of rocks, both igneous and sedimentary, such as spherulitic felsite, felspar-porphry

vein-quartz, quartzite, grit, chert, and jasper; and Dr. Teall has found from microscopical examination that the felsites and porphyries are "identical in all essential respects with the felsites [*i.e.* devitrified rhyolites] belonging to the Uriconian Series of Shropshire."

In these pebbles, therefore, we seem to have traces of a vanished formation, of later date than the Hebridean gneiss, from which the component materials of the Torridonian deposits were principally derived. It would be interesting to compare the volcanic rocks with the felsites and porphyries which occur in Sweden and seem to occupy an intermediate position between the equivalents of the Hebridean and Torridonian Series.

In the extreme north between Cape Wrath and Loch Inchar, the Torridonian is not more than 1200 to 1500 feet thick, but farther south the beds not only thicken but another set of beds come in at the base, till round Loch Maree and Loch Torridon its thickness amounts to more than 8000 feet. The whole formation has been divided into three groups by Messrs. Peach and Horne, as shown in the following table.

Groups.	Nature of Materials.	Thickness.
3. Aultbea Group	Chocolate-coloured sandstones and flags with grey flags and partings of shale	2000 to 4500
2. Applecross Group	Coarse arkose with pebbles of quartz, quartzite, etc.	5000 to 7000
1. Diabeg Group	Red sandstones and mudstones with grey grits and black shales and calcareous bands	500 in Cairloch 4400 in Kishorn

Still farther south in Skye Mr. Clough finds that the lowest or Diabeg Group expands in a remarkable way, and that it there attains a thickness of about 7000 feet, so that although in that island the Aultbea Group is not represented there are 12,000 feet of Torridonian deposits, and may have been as much as 16,000 feet.¹⁰

Mr. Clough has made the following subdivisions of the Torridonian of Skye in descending order:—

- e. Applecross Group. Red and chocolate arkoses with pebbles of various rocks; estimated at 5000 feet.
- d. Kinloch Beds. Alternating beds of dark-grey sandy shale and fine grey or buff grit; about 3500 feet.
- c. Seamraig Beds. Greenish-grey grits with some beds of sandy shale; 2600 feet.
- b. Loch na Dal Beds. Sandy shales and fine grits; 600 feet.
- a. Epidotic grits and conglomerates. About 300 feet.

The four lower divisions represent an expansion of the Diabeg Group, and it will be noticed that they include two important developments of shaly deposits. From the facts recorded in the Geological Survey Memoir it may be inferred that the Torridonian Series originally presented a succession of overlapping beds, the lower members thinning out northwards beneath the higher beds as indicated in the diagram, Fig. 5. In other words we may suppose that deposition began in the south and extended northwards as land in that direction was gradually submerged.

Small patches of Torridonian sandstone occur in the island of Lewis, and show that the series had a western extension; outliers of it have also been detected beneath the Cambrian rocks of East Sutherland, so that it must originally have occupied a very large area, and probably extended beyond the shores of Scotland both

Fig. 5.—DIAGRAM OF THE ORIGINAL SUCCESSION OF TORRIDONIAN DEPOSITS.

3. Aultbea Group.

2. Applecross Group.

1. Diabeg Group.

on the east and on the west. It was, however, to a large extent destroyed and broken up into isolated tracts during the time which elapsed before the deposition of the lowest Cambrian.

The most southerly occurrence of the Torridon Series in Scotland is in the Isle of Islay, where there is an interesting and suggestive collocation of Archæan rocks.¹¹ Hebridean and Torridonian are only found in the western part of the island, while the eastern and larger part is occupied by two groups, quartzites and schists, one of which is a continuation of the Grampian Series. The two tracts are separated by a thrust-plane which runs from Loch Gruinard on the north, through Loch Skerrols and near Bridgend, to the east side of Laggan Bay on the south. The Torridonian sequence resembles that of Skye, having an epidotic grit and conglomerate at the base, overlain by a thick group of grey slates and grits, which are succeeded by the Bowmore grits, a series of red, green, and grey feldspathic grits or arkoses like those of the Applecross Group. Owing to intense plication no estimates of thickness can be made. Moreover, the whole series has been affected by dynamic metamorphism and converted into slates, phyllites, and more or less schistose grits.

The Grampian Series of Eastern Islay comprises the following members in descending order :—

4. Islay limestone.
3. Black slates and phyllites } = Ballachulish limestone and slates.
2. Phyllites with thin quartzose bands (=Striped Series).
1. Quartz-schists (=Appin quartzite).

This series is overlain unconformably by quartzites and shales which greatly resemble those of the Cambrian in Skye, but as no fossils other than worm-tracks and annelid-burrows have been found, the correlation is not proved. These newer quartzites have a conglomerate at the base which contains pebbles of all the older rocks in the island, and includes many of the Islay limestone.

In Islay, therefore, not only is the Grampian Series brought into apposition with Hebridean and Torridonian rocks, but there is evidence which amounts to a strong presumption that it is of pre-Cambrian age. It is, moreover, a noteworthy fact that nothing comparable to the Moine Series has been found in the island.

The Geological Survey has not yet ventured to record any definite conclusion with respect to the relative ages of the Moine schists, the Torridonian, and the Grampian Series. In the absence of any official declaration it is only possible to indicate the trend of the evidence, so far as it has been published in the Reports and Memoirs of the Survey. Reviewing this evidence one cannot fail to be struck with the fact that on the western side of the great thrust-planes, where the succession is clear and post-Cambrian disturbance is small, only two Archæan Series are found, i.e. the Hebridean and the Torridonian. On the other hand, in the much larger area to the eastward there are at least three such series, Hebridean, Moine, and Grampian; further, it seems very probable that both of the two last are newer than the Hebridean, and also that both are pre-Cambrian, but the relative age of the Moine schists is still a matter of doubt.

Two alternatives present themselves, either (1) the Moine Series may be a separate intermediate system, or (2) they may be merely sheared and metamorphosed Torridonian deposits of the Skye facies.

If they are to be regarded as a separate Mesarchæan System (either with or without the Grampian Series), two awkward questions have to be answered, (a) what has become of the Torridonian strata east of the Moine thrust? and (b) why is there nothing in the western, except the Torridonian, that is comparable to the Moine schists? The evidence recently disclosed enables us to assume that the Moine schists were originally a series of

felspathic sandstones and sandy shales; moreover there is reason to believe that they are divisible into four zones, the first and third being purely arenaceous, the second and fourth pelitic or argillaceous. Again, there is evidence that where they are in contact with the Hebridean there is an unconformity between the two. Thus there must have been a striking resemblance between the Torridonian and the Moine schists in their original condition.

The idea that the Moine schists and flags are only Torridonian in an altered form is by no means new, for it was suggested as long ago as 1899 by Sir A. Geikie in the following passage:—¹² "Probably the Torridon sandstone was largely drawn upon in the process of the manufacture of these schists, and there may also have been Cambrian or even later sediments which underwent the same conversion into a foliated crystalline condition." The progress of investigation has tended to eliminate the latter possibility, but to confirm the first supposition.

Thus Messrs. Horne and Teall, writing of the eastern schists in the memoir on the N.W. Highlands, pointed out that in several cases tracts of Torridon sandstone below and near the thrust-planes show a tendency to break down into schistose grits, and again that the Moine schists which immediately overlie the Moine thrust are less completely crystalline than those lying farther to the east, similar cataclastic structures being not uncommon in them, so that "the question has arisen as to whether they represent crystalline schists more or less broken down or sedimentary rocks which are on the way, so to speak, to become Moine schist" (*op. cit.* p. 600).

On the other hand, Dr. Horne and Professor Gregory hold that the Moine schists are pre-Grampian, because in several localities the Grampian Series rests directly upon them. Some of these cases are explicable by overthrusts, but in Glen Tilt the Blair Athol limestone lies unconformably on an eroded surface of Moine schist. These geologists consequently believe in the existence of four Archæan Systems in the following ascending order—(1) Hebridean, (2) Caledonian (*i.e.* Moine schists), (3) Dalradian (= Grampian), (4) Torridonian.

2. Ireland

The Archæan rocks of Ireland deserve a brief notice because they are for the most part a continuation of the Scottish Grampian Series. There are two large areas in Ireland where such rocks come to the surface from beneath the Palæozoic formations. One of these areas includes the greater part of Donegal and the western part of Derry with a portion of Tyrone; the other comprises the

western parts of Mayo and Galway, and the two areas are almost connected by a narrow tract of the same rocks, which runs from south-west to north-east for a distance of 60 miles, extending from near Castlebar through the Ox Mountains to Hamilton in Leitrim.

So far as yet known fundamental gneiss is only exposed in Tyrone, the gneisses of the western areas being all intrusive gneissic granites. There is no great fault or thrust-plane separating unaltered Hebridean from later schists, as in the north-west of Scotland; or if such a plane exists it must lie outside the north-west coast of Donegal. Neither is there anything to correspond with the Torridonian or with the Moine schists of Scotland.

(1) **Fundamental Gneiss.**—In Tyrone this forms a long narrow tract of hilly country extending north-east from near Carrickmore to Slieve Gallion, about 18 miles, and having a maximum width of 3 or 4 miles. Sir A. Geikie has described it as "an undoubted core of Archæan gneiss, resembling in all essential characters the Lewisian rocks of the north-west of Scotland."¹³ More recently its position has been discussed by Professor G. A. J. Cole, who also regards it as the oldest local rock and mentions the occurrence of a much later intrusive granite, which includes fragments of the gneiss and of the schists which flank the ridge.¹⁴

(2) **Donegal Schists.**—The gneiss of Tyrone is surrounded by a group of coarse volcanic agglomerates—tuffs and lavas—which pass up into green chloritic schists and silvery mica-schists like those of the Grampian Series. The lavas are chiefly basic and are often plainly amygdaloidal and on the north-west side of the ridge are singularly fresh and unaltered, a condition which Sir A. Geikie attributes to the protection afforded them by the ridge during the time of great pressure from the south-east. The tuffs have suffered much more from deformation and are now silky green chloritic schists, but they seem originally to have been derived from the same magma as the lavas (*op. cit.* p. 42).

Farther to the north-west, in Donegal and in Londonderry, these volcanic rocks are succeeded by quartzites and black schists with bands of crystalline limestone. A similar assemblage of sedimentary and igneous rocks is found in Galway, Mayo, and the Ox Mountains. These of Slieve Gamph and the Ox Mountains have been recently described by Mr. M'Henry, who considers the descending succession to be as follows:—¹⁵

4. Quartzite passing down into a sheared conglomerate which is often a "Boulder-bed."
3. Limestone, often altered to whitish marble or green opicalcite.
2. Black shales and graphitic grits.
1. Pebbly grits with bands of black shale or schist.

This series has been extensively invaded by igneous rocks, both basic and acid, the dykes and veins of the latter cutting through the former which are consequently the older, though all are compressed and sheared by still later movements of the crust.

The "Boulder-bed" has been identified in varying thickness all over Galway, Mayo, and Donegal. The boulders in it are almost all of an unfoliated granite, unlike anything now visible at the surface. They are mostly angular or sub-angular, only a few being rounded, and are sparsely distributed in a fine-grained matrix. They vary in size up to $3\frac{1}{2}$ feet across, and Mr. M'Henry has suggested that the bed is a genuine boulder-clay of glacial origin, but its constant superposition on a limestone over such a large region makes this rather unlikely.

Besides the dykes and veins of igneous rock there are large tracts of more or less foliated granite which have often the appearance of being interbedded with the schists, but they sometimes pass into banded gneiss, which is thus shown to be a composite rock formed by the intrusion of tongues of granite into the schists, the banding being due partly to the incorporation of the latter and partly to a flow structure developed in the granite itself, while the whole mass has been sharply flexured, compressed, and sheared by the subsequent pressures.

Describing the granitic dome of Ardara in West Donegal, Professor Cole¹⁶ points out that the pure granite of the central mass has a border zone of banded gneiss, which is of composite origin and not an original gneiss nor a mylonised rock. "The phenomena," he says, "are those of intrusion along the pre-existing foliation-planes of a schist, and a good gneissose rock results, set with inclusion-flecks, in which these foliation-planes are still apparent."

Whatever may be the age of these intrusive gneissic granites, that of the schistose series seems now to be practically settled by the discovery of Arenig rocks in Mayo and their superposition on the schists south of Killary Harbour. This disposes of the old view that the schists were only metamorphosed Ordovician sediments.

3. *Wales*

Archæan rocks come to the surface both in North and South Wales; they occupy large parts of Anglesey and smaller areas in Carnarvonshire, while in Pembroke round St. David's they are known as the *Pebidian Series* (see map, Fig. 16).

Anglesey.—Much has been written about the Archæan rocks of Anglesey, and many conflicting views have been published. A good description of the rocks themselves was given by Ramsay in

his memoir on the "Geology of North Wales"; the plutonic complex of the central area was described by Dr. C. Callaway¹⁷ in 1902; Sir A. Geikie noted the resemblance between some of the schists and those of Scotland; the north-western part of the island was mapped by Dr. C. Matley, and the Ordovician tracts separated from the Archæan schists in 1899.¹⁸ Finally, during the last fifteen years the whole island has been re-surveyed by Mr. E. Greenly, whose map and memoir will shortly be published by the Geological Surveys. Meantime I am indebted to Mr. Greenly for the following condensed account of the pre-Cambrian rocks.

Though no fossiliferous Cambrian rocks have been found in the island the relation of the schistose complex to the Ordovician, and of the Ordovician to Cambrian on the mainland, leaves no doubt of the pre-Cambrian age of that complex.

Rocks of Archæan age reach the surface in five principal areas and in several smaller inlying tracts. They consist for the most part of greenish schistose grits, alternating with gritty phyllites and fine chloritic mica-schists; there are also other mica-schists, about the origin of which some difference of opinion still exists. There are, moreover, many bands of quartzite and of limestone, some being of considerable thickness.

Across the central part of the island, ranging south-west and north-east, is an axis-like tract of highly crystalline rocks, including various types of basic and acid rocks which have a deep-seated aspect, *i.e.* gneisses, hornfelses, diorite, and granite. The relations of this group to the sedimentary series have been much obscured by subsequent movements, but some of the granites are certainly intrusive into the adjacent rocks which are now in the condition of crystalline hornfels.

Interbedded with the sedimentary rocks in many parts of the island are bands of basic igneous rock. Most of these are now chloritic and hornblendic schists, with (locally) large masses of glaucophane schist. Some of the chloritic schists were probably volcanic tuffs, but here and there, especially in the south-west near Newborough, the original structure is beautifully preserved, and the lavas are of that pillowy or ellipsoidal form and variolitic type with which radiolarian cherts are so often associated.

No unaltered cherts have been found, but nodules and lumps of red jasper occur abundantly in these lavas, filling the interspaces between the ellipsoids. Similar jasper also occurs in the form of nodules and thin beds in many of the limestones, and seams of fine jaspery purple phyllite are also of frequent occurrence. From this mode of occurrence these jaspers have been regarded by some writers as altered radiolarian cherts, but their radiolarian origin has not yet been proved.

The whole Archæan complex of Anglesey was affected by very powerful pre-Ordovician earth-movements. In some parts they are closely folded and minutely corrugated, in other places so sheared and torn that the harder and more resistant beds have been broken up and are now merely a series of phacoids or lenticular masses, floating as it were in a kind of matrix formed out of the softer beds. Further, the movements induced varying degrees of metamorphism, so that there are few of the rocks which have not been converted into more or less crystalline schists.

Under these circumstances and in the absence of fossils it has not been found possible to establish anything like an order of succession; at the same time it is nearly certain that more than one of the Archæan systems is present in the island. There is even some reason to think that the central complex of gneissic rocks is a fragment of a *massif* older than the great sedimentary series, but its outer members are so welded to that series by a common foliation that direct evidence can hardly be expected.

The general sequence of events seems to have been as follows:—Upon an ancient floor, of which hardly anything is known, but which was composed in part at any rate of plutonic rocks, a great series of grits and shales, with quartzites and limestones, was laid down. At some period during the deposition of these sediments a volcanic episode occurred, and basic lavas with ellipsoidal structure were poured out on the sea floor, after which the interstices of the lava-flows were infiltrated with silica in the form of chert.

After the accumulation of all these sediments and volcanic materials, but before the beginning of Ordovician time, crust movements on the most powerful scale supervened, causing the whole complex to be crushed, folded, and sheared in a most complicated manner. The rocks were in fact practically reduced to the condition in which they are now found before the deposition of the oldest local members of the Ordovician Series, and probably before the commencement of Cambrian time.

Carnarvonshire.—Rocks similar to the sedimentary series of Anglesey are found again on the western side of the Lleyn promontory and form a long strip from Bardsey Island to Nevin, with a width of from 1 to 2 miles. This district exhibits the same series of schists and slates, of purple and green colours, with broken bands of limestone and quartzite, and a similar association of basic lavas and tuffs with jaspery infiltrations. According to Mr. J. F. Blake there is rather a larger development of volcanic material than in Anglesey, especially in the south-west where there is much volcanic ash and some masses of coarse agglomerate.

Two other small strips of pre-Cambrian rocks come to the

surface farther north, one extending from Llanllyfyn on the south to Penrhyn on the north, a distance of about 15 miles, with a maximum width of 2 miles (see map, Fig. 19). This tract consists of a rhyolitic felsite succeeded by breccias and schists.

A second tract extends from Carnarvon to Bangor, a distance of about 10 miles, with a width of over a mile in the central part. This latter has been well described by Professors Bonney and Hughes,¹⁹ who have shown that there are three sets of rocks in the ridge, (1) a granitoid rock at the southern end (Twt Hill), (2) a reddish-purple quartz-felsite, (3) a series of felspathic grits, slates, and agglomerates (the "altered Cambrian" of the Geological Survey). These last are overlain by other conglomerates of Lower Cambrian age. With respect to the relations of these rocks the following facts appear to be well established :—

- (1) That the quartz-felsite was a rhyolite, and probably a rhyolitic lava-flow.
- (2) That between this rhyolite and the basal Cambrian conglomerate there is a series of volcanic and sedimentary deposits which are not less than 3000 feet thick.
- (3) That the Cambrian conglomerate contains many fragments of the quartz-felsite and some of granitoid rock (consisting of quartz and felspar) like that of Twt Hill.

This set of pre-Cambrian rocks has been called the Bangor Series, and it should be noted that this series differs from that found in Anglesey and the Llyn in several particulars. The volcanic rock is acid not basic, all the rocks are less altered and less flexured, and they directly underlie the base of the Cambrian System.

Pembrokeshire.—The oldest rocks in South Wales crop out in the neighbourhood of St. David's (see map, Fig. 16). A pre-Cambrian age was first claimed for them by Dr. H. Hicks in 1871, and the results of his examination of the district were published in several papers.²⁰ His conclusions may be thus summarised : that the base of the Cambrian System is marked by a conglomerate containing pebbles of the underlying rocks ; that this conglomerate rests on a series of schistose volcanic tuffs and breccias, under which is another set of quartz-felsites and halleflintas. Below these again comes a granitoid rock which he regarded as a still older mass of metamorphic rock. To this last he gave the name of *Dimetian* ; the overlying volcanic series he called *Pebidian* (see Fig. 6).

In 1883, however, these conclusions were called in question by Sir A. Geikie, who maintained the correctness of the Geological Survey mapping, holding that the granite is an intrusive mass of igneous rock, and that the volcanic series (*Pebidian*) is a down-

Fig. 6.—SECTION FROM NEAR CASTELL TO PORTH CLAIS (PEMBROKESHIRE) by the late Dr Hicks. Distance about 14 mile

ward continuation of the Lower Cambrians, the apparent break between them being only a surface of contemporaneous erosion.²¹

Still more recently (1908) the district has been studied and mapped by Mr. J. F. N. Green,²² who appears to have finally established the relative positions and ages of the rocks concerned. He confirms the existence of a basal Cambrian conglomerate and of an extensive pre-Cambrian Series, which is the Pebidian of Hicks.

These Pebidian rocks occupy an area of about 7 miles in length, with a maximum width of 2 miles; and according to Mr. Green they consist almost entirely of trachytic and felsitic tuffs, more basic in the lower part, more acid and felspathic in the higher part, the total thickness being over 3000 feet. A well-marked band of conglomerate occurs in the middle of the series and lenticles of shale are seen at several horizons. There do not seem to be any interbedded contemporaneous lava-flows, but rounded pebbles of rhyolite, trachyte, and andesite occur in the tuffs.

The materials of this series are evidently the products of a large volcano or group of volcanoes spread out under water, but whether on the floor of lake or sea cannot be determined. At some later epoch, but still in pre-Cambrian time, the series was invaded by a large intrusive mass of granite and by a number of quartz-porphry dykes which probably proceed from the deeper parts of the granitic mass.

We arrive, therefore, at the conclusion that Hicks was correct in his reading of the main stratigraphical sequence, but wrong about the age of the granite; while Sir A. Geikie rightly interpreted the relations of the granite, but was mistaken about the base of the Cambrian and in denying the existence of Archæan rocks in Pembrokeshire.

4. *England*

Rocks of Archæan age rise to the surface in the following localities:

(1) Shropshire (Longmynd, Wrekin, etc.), (2) Warwickshire (Nuneaton), (3) Leicestershire (Charnwood Forest), (4) The Malvern Hills, (5) Devon (Start Point area), (6) Cornwall (Lizard area).

Shropshire.—The largest and most complete area in England is that of the Longmynd, Caradoc, and Wrekin districts. These tracts are shown in Fig. 21. That of the Longmynd has a length of about 10 miles along its western border, with a further outcrop on Haughmond Hill; its greatest breadth is about 6 miles, and it is bounded on each side by lines of fault, and inside the eastern fault another narrow strip is exposed to the south of the main outcrop.

The exact age of the Longmynd rocks cannot be determined by

superposition, for their base is not seen and the oldest rocks which overlie them are Silurian. Outside this central area are small tracts of other rocks which are demonstrably pre-Cambrian, but they are chiefly of volcanic origin while those of the Longmynd are sedimentary. Lastly, there is a small faulted inlier of micaceous schist near Rushton which may be older than any of the others.

The volcanic series is known as the *Uriconian*, from the hill called the Wrekin and the Roman town of Uriconium at its foot. The mass of the Wrekin ridge is made up of a succession of rhyolitic lavas with interbedded bands of ash, grit, conglomerate, and agglomerate. Midway along the ridge there is an intrusive mass of dolerite, and at each end (*i.e.* on Ercal Hill and Primrose Hill) are patches of granitoid rock which may be intrusive or may belong to an older series. This uncertainty is due to the fact that the junctions appear to be faults,²³ but pebbles in a conglomerate near the Wrekin prove that the rocks of the surrounding country at the time of its formation consisted principally of (1) a coarse granitoid gneiss like that of the Wrekin, (2) crystalline schists, both quartzose and micaceous, and (3) grits which have clearly been part of a sedimentary series.

Rocks similar to those of the Wrekin occur in the Wrockwardine Hills to the north-west, as well as in the Caradoc and Cardington Hills near Church Stretton, and this volcanic series everywhere strikes nearly east and west, while the Longmyndian and Cambrian rocks strike north-east and south-west (see map, Fig. 21). On the western side of the Longmynd, Pontesford Hill is largely made up of rhyolitic lavas like those of the Wrekin, with intrusive dolerites.

The *Longmyndian* or sedimentary series of the Longmynd is divisible into an eastern and western portion. The eastern part appears to be the older, and if there is no reduplication of beds the succession is as follows (see Fig. 7), in descending order :—

5. Greenish slates weathering purple, with some grits.
4. Hard greywacke (indurated sandy beds).
3. Purple slates.
2. Banded slates and greywackes.
1. Soft dark shales.

The apparent thickness of these rocks is over 15,000 feet, and they dip regularly to the north-west, the annelid markings and rain-spots on their upper surfaces proving this to be the true dip, and that we follow an upward succession in going from east to west. No definite fossils have been obtained except some impressions, which may be those of a *Lingulella*.

Passing westward this series is succeeded by another set of beds, consisting (1) of reddish felspathic grits with a thick band of con-

glomerate in the middle, (2) hard purple slates, and (3) purple and reddish-brown grits with lenticular beds of conglomerate. It is uncertain whether this is a true succession, for it is just possible that the double set of reddish grits and conglomerates is a reduplication.

The relation of the western series to the eastern series is also a point of dispute. Professor Blake believed the former to be unconformable to the latter and to be of the same age as some of the grits in the Uriconian Group. In his view the eastern or grey series is the oldest rock-group in the district and the Uriconian is newer. In favour of this view it may be remarked that the basal Cambrian sandstones have only been found in contact with the Uriconian and not upon any part of the Longmyndian. On the other hand, numerous fragments of the Uriconian rhyolites occur not only in the conglomerates of the western series, but also occasionally as small fragments in the grits of the eastern series. The evidence of actual unconformity is considered very dubious by Dr. Callaway, who also points out that the strike of the two Longmyndian Series is parallel (from N.N.E. to S.S.W.), while that of the Uriconian is quite different (from east to west).²⁴

The balance of evidence seems to be in favour of Dr. Callaway's view, in which case the order of succession would be (1) Uriconian, (2) Eastern Longmynd Series, (3) Western Longmynd Series. In this connection it may be mentioned that this last (the red series) has a close lithological resemblance to the Torridon sandstones, and it will be remembered that the conglomerates of the latter contain pebbles of a Uriconian rhyolitic type. This tends to confirm Dr. Callaway's opinion and suggests a comparison between the Longmyndian as a whole and the Torridonian of Scotland.

Malvern Hills.—The oldest rocks of the Malvern Hills are also pre-Cambrian, and are interesting because the greater part consists of highly crystalline gneissic rocks, which are probably altered igneous rocks, and are comparable to the Hebridean gneisses of Scotland and Ireland. This group is known as the *Malvernian*. Side by side with these is a small tract of rocks comparable with the Uriconian of Shropshire, and consisting of rhyolites, andesites, basalts, and felspathic tuffs.²⁵ There is nothing here comparable to the Longmyndian Series, but the district has undergone an enormous amount of compression with plication, shearing, and faulting, as will be seen from the section, Fig. 8.

Charnwood Forest.—Small tracts of volcanic tuffs and breccias, resembling those of the Uriconian, occur at Barnt Green near Birmingham and at Caldecote near Nuneaton, and are in both cases covered unconformably by Cambrian strata. A larger tract

of similar rocks forms the upland district of Charnwood Forest in Leicestershire.

The "Charnian Series" has been described by Messrs. Bonney and E. Hill,²⁶ and more recently by Professor Watts,²⁷ from whose memoirs the following account is taken. The exposures (partly concealed by Trias) extend over an area about 8 miles long by 5 in breadth, and the strike of the rocks is from north-west to south-east, the general structure being that of a broad anticline broken by faults and flexures. The apparent thickness of the beds exposed, as estimated from a section drawn by Professor Watts, is about 3500 feet, but neither base nor top is seen.

The oldest rocks (Blackbrook Beds) are hard greenish slates and hornstones, which seem originally to have consisted largely of volcanic dust; with these are some fine gritty beds containing visible quartz-grains, but they are nevertheless hard flinty rocks. The overlying (Maplewell) group consists of coarse volcanic

Fig. 8.—SECTION ACROSS THE HEREFORDSHIRE BEACON.
By Professor T. T. Groom (*Quart. Journ. Geol. Soc.* lvi. p. 141).
Tr. = Trias. Malv. = Malvernian. F.F. = Faults.
LL to MS₂ = Silurian Rocks. Ur. = Uriconian.

breccias and grits with tuffs and ashes, some of the latter being of such fine grain that they form hornstones and slates, either green or purple in colour.

The highest group (Brand Beds) has a conglomerate at the base which contains rounded pebbles of felsite, quartz, quartzite, and slate; this passes up into brown and purple quartzites with some interstratified sandy shales, in which what seem to be worm-casts have been found. These beds are succeeded by green and purple slates (Swithland slates).

In the north-west corner of the area, forming Bardon Hill and Peldar Tor, there are irregular masses of a porphyritic andesite and dacite, associated with coarse agglomerates. These seem to indicate the site or proximity of a volcanic vent. In the southern part of the area there are large intrusive masses of augite-syenite, and on the east is the hornblende granite of Mount Sorrel, a rock which is largely quarried for road-metal.

Devon and Cornwall.—The only other exposures of Archæan rocks in England are the two small areas of the Bolt and Start

district in Devon and the Lizard promontory in Cornwall, and in neither case can the Archæan age of the rocks be proved because the adjacent strata belong to the Devonian System.

The area in Devon is that part of the county which lies inside the headlands of Start Point, Prawle Point, and Bolt Head. It has a length of about 9 miles with an extreme width of 3 from north to south. The rocks of which it consists are divisible into two groups, a lower set of mica and quartz schists and an upper one of green hornblende-epidote schists, known as the Green schists, and obviously altered basic igneous rocks.

The general structure of the eastern half of the area is that of an irregular anticline, bent over and inverted on the southern side. The northern border is believed to be a fault, and there is everywhere a rapid if not immediate change from foliated rocks to Devonian slates which are comparatively unaltered, except by cleavage and dislocations. Some geologists have maintained that the schists are only highly altered Devonian slates, and have appealed to the facts,—that there is a progressive increase in the intensity of the cleavage in these slates south of Brixham; that there are appearances of a passage from slates to schists in some places along the boundary line; and that the general strike of both series is the same, *i.e.* from west to east. It must be remembered, however, that the dominant flexuring of this part of England dates from late Carboniferous time (Armorican folding), while the appearance of a passage may be caused by the occurrence of crushed and broken schists between two lines of fault. If this area is altered Devonian the metamorphism can only be due to the influence of some local cause, such as the existence of a subterranean mass of granite, but the balance of evidence seems to be in favour of their Archæan age.²⁸

C. ARCHÆAN ROCKS IN EUROPE

Outcrops of Archæan rocks, or what are generally regarded as Archæan rocks, occur in France, Spain, Switzerland, Austria, Bohemia, Saxony, the north of Russia, Finland, and Scandinavia. Only the more important of these areas can here be described.

1. *France*

In France the chief exposures are found in the north-west (Brittany and Normandy) and in the Central Plateau.

Brittany.—Pre-Cambrian rocks, with associated masses of

granite, occupy large parts of Brittany, together with the western portions of Normandy, Maine, and Anjou. They have been well described by Professor C. Parrois, from whose memoirs the following account has been compiled.²⁹ He and other French geologists are inclined to divide them into two main series which they call (1) Archæan and (2) Brioverian, but as they again subdivide the lower series into three portions, and as no break has been observed between any of the divisions, they can be equally well arranged in three series, thus :—

3. Phyllades des St. Lo (= Brioverian).
2. The mica-schists of Groix.
1. The schists of Audierne and gneiss of Quimperlé.

The oldest group is a complex of which a granitoid rock sometimes seems to be the oldest member, but more often the lowest rocks are mica-schists which include bands of ribboned gneiss, white leptynite, amphibolite, and eclogite. In the south these rocks form a continuous tract from 10 to 16 miles in breadth extending from the Bay of Audierne on the west to the valley of the Loire, a distance of about 140 miles. In the north there are two bands of similar rocks, one passing from Brest to Leon with probably a submarine continuation to Guernsey, the other near St. Malo.

Professor Bonney informs me that he has not seen anything in Western or Northern Brittany, nor in the Cotentin, which is quite comparable with the Hebridean and Malvernian gneiss, and he is inclined to doubt whether such gneiss exists in the region.

The schists of Groix seem to be an upward continuation of the series, being truly crystalline schists of micaceous, chloritic, graphitic, and sillimanitic varieties, with subordinate bands of quartzite (sericitic and graphitic), hornstone, and pyroxenic marble (cipolin). These resemble the Loch Maree Beds.

The Brioverian Series consists of much less altered rocks of a typical Eparchæan character. They exhibit three different facies in different parts of the region : (a) the facies of St. Lo in Normandy and of Central Brittany, comprising the phyllades of St. Lo and Lamballe, the phyllades of Gourin, which include a band of limestone, and the green flags of Neant at the top; (b) the Trégorrois facies in the north of Brittany, consisting of phyllades and quartzose rocks with interstratified eruptives (porphyrites and diabases); (c) lastly, the southern facies, which consists mainly of shales with interbedded bands of coarse feldspathic sandstone, recalling the Torridonian of Scotland and suggesting that the Brioverian land lay to the south of Brittany.

These Brioverian deposits are unconformably overlain by the

purple conglomerate which forms the base of the Cambrian System, and no fossils have been found in them except some microscopic bodies which resemble Radiolaria and Foraminifera.

The Central Plateau.—This is a large region extending from La Chatre and Moulins on the north (Departments of the Indre and Allier) to the Cevennes in the south, a distance of about 220 miles, while, between Chalus and Brive on the west to the valley of the Rhone on the east, its breadth is over 160 miles.

This great area consists of a complex of granites, granulites, gneisses of several kinds, micaceous schists, and phyllites, but to what extent these rocks are of pre-Cambrian age is at present uncertain, because the Palæozoic rocks by which they are doubtless surrounded are almost everywhere concealed and overstepped by Mesozoic strata. It is only in the southern border (in the Tarn and Herault Departments) that rocks of Palæozoic age are found in contact with them.

The granites are doubtless all intrusive rocks and the granitoid gneisses may be foliated portions of the same intrusions, like those of Donegal; while the more highly crystalline portions of the complex are probably those which are most closely associated with these intrusions, being merely the more altered portions of the mica-schist series into which the igneous rocks were intruded. No break or clear plane of separation has been detected in any part of the schistose series, but in several districts along or near the borders of the region there are tracts of still less altered and obviously sedimentary rocks, including arkose sandstones, quartzites, slates, and phyllites comparable with the Brioverian. A long strip of such rocks occurs between Brive and Tulle in the Corrèze, where Messrs. de Launay and Mouret have described the following descending succession:—³⁰

Dark-grey slates and argillites.

Green slates and phyllites.

Greenish sericitic and micaceous quartzites.

Similarly in the Cevennes on the outer borders of the gneissic rocks there is a considerable thickness of satiny schists or phyllites (*schistes luisantes*). In the district of Montagne Noir these schists include bands of limestone and appear to pass up into a set of shales and limestones which contain Cambrian fossils. Hence M. Bergeron regards the whole mass of the Montagne Noir as Cambrian,³¹ repeated in many parallel flexures and becoming more and more metamorphosed toward the central axis of the mass till the rocks pass into mica-schists and gneisses. He states that the limestones resist alteration longer than the shales, but gradually

become greenish from the development of augite or hornblende crystals, which increase in size till the rock passes into amphibolite or pyroxemite. By others, however, some of the phyllites are considered to be of Brioverian age.

2. *Austria and Switzerland*

A long tract of crystalline rocks, some of which are probably Archæan, extends from the Graian and Cottian Alps on the borders of France and Italy through the southern part of Switzerland (Pennine, Lepontine, and Rhætian Alps), and is continued eastward through the Tyrol into Carinthia and Styria.

According to von Hauer's map of the Eastern Alps, the fundamental rock of that region is a group of banded hornblendic and micaceous gneisses, which he terms "the Central Gneiss"; outside this is a series of micaceous schists, followed by a formation called the *Thonschiefer*, *i.e.* silvery or sheeny schists.

The gneisses of the "Central" group are only occasionally exposed along the central axis of the chain. Those of the Velber-Tauern Pass and the neighbouring Gross Venediger are thus described by Professor Bonney: ³² "These, whether micaceous or hornblendic, recalled to my mind certain members, but not the most coarsely crystalline, of the Hebridean of Scotland and the Laurentian of Canada, which are often distinctly modified by subsequent pressure. We also find slightly foliated, coarsely crystalline, granitoid rock with nodes or enclosures, probably a granite subsequently modified, the upper part of the mountain chiefly consisting of the latter rock." The Gross Venediger rises to a height of 12,000 feet.

Overlying these gneisses and apparently passing down into them is a series of fine-grained gneisses and mica-schists, often distinctly banded with white (quartzose) and dark (biotitic) layers, and this bedding-foliation is often modified by a subsequent cleavage-foliation. With these rocks are associated bands of porphyritic gneiss which Professor Bonney regards as igneous rocks intruded into them before the production of the earlier foliation.

The Thonschiefer Series is a well-defined group of rocks which extends throughout the Eastern Alps from the Swiss border nearly as far as Gratz. It consists mainly of leaden-coloured micaceous schists which have glistening sheeny surfaces, but it includes bands of a more quartzose schist with some of calc-schist and crystalline limestone.

Again, in the Western Alps of France, Italy, and Switzerland, Professors Bonney, Gastaldi, and others have recognised a similar succession of (1) coarse banded gneisses apparently succeeded by

(2) finer gneisses and mica-schists, often traversed by dykes of serpentine and epidiorite, and finally a series (3) of micaceous, calcareous, and chloritic schists, between which and the older schists there is a marked lithological difference and contrast.

Recently, however, grave doubts have been thrown upon the view that these are all Archæan rocks, upon the age of the gneiss by Professor J. W. Gregory,³³ and upon that of the *schistes lustrés* by Kilian and Parona. Professor Gregory admits the apparent sequence, but fails to find anything like a continuous band of "central gneiss" as represented on certain maps; only independent isolated masses of gneiss which appear to be intrusive granites of very recent date. Monsieur Parona, again, has discovered layers of chert containing Radiolaria in the silvery schists, and the generic assemblage suggests a Carboniferous or even Mesozoic age.

Professor Gregory has specially studied the gneisses of the Cottian Alps and finds that there is clear evidence of contact-metamorphism both in the gneisses and the adjoining schists; that the gneisses invade different parts of the schist series with transgressive junctions; that they include large blocks of the schists and serpentines; that the schists are occasionally traversed by dykes of aplite which appear to be apophyses of the gneissic granite, while the latter is not itself cut by *any* of the later igneous rocks.

He concludes that the gneiss is really a granite of Pliocene date and that the silvery schists are mainly Palæozoic and probably of Carboniferous age. Thus if these views are correct the only Archæan rocks in the Cottian, and indeed in all the Western and Italian Alps, are the series of mica-schists and calc-schists into which the Tertiary granite has been injected.

3. Bohemia

Another large area of Archæan rocks is exposed in Bohemia and Saxony, extending from the valley of the Danube on the south through the Bohemian Highlands (Bohmer Wald) and the Erzgebirge, and as far as Chemnitz and Dresden on the north, while eastward it ranges into Moravia. In the northern part of this region there is a basin of Palæozoic strata extending from Pilsen to Prague, and on the border of this the highest Archæan rocks can be seen to pass below the Cambrian strata.

The Archæan rocks of this region seem to resemble those of the Eastern Alps, and a similar threefold division of them has been made, those supposed to be the oldest consisting of gneisses much interpenetrated by granites. In apparent succession to these are mica-schists and phyllites, with intercalations of amphibolites,

serpentines, eclogites, and crystalline limestones, evidently a series of metamorphosed stratified rocks. Finally on the borders of the Palæozoic basin these schists graduate upward into dark-grey clay-slates (Thonschiefer) with some more siliceous layers of lydite or hornstone. These are the Prizibram shales which formed the base of Barrande's "*Stage A*," but as they are overlain unconformably by Cambrian conglomerates they are now separated from the rest of that stage and classed as Archæan.

As in the case of the Alpine Series much doubt has recently been thrown on the old interpretation of the stratigraphy of this area. Some of the gneisses, as well as the granites, are now regarded as intrusive rocks, and no break or definite unconformity has been detected in the series, so that the whole of it may belong to the later portion of Archæan time; at any rate nothing demonstrably

FIG. 9.—SECTION THROUGH PART OF THE BOHMER WALD (Gumbel).

C. Cambrian.	K. Cryst. limestone.	Gl. Mica-schist.	Gyl. Gneissic granite.
Ph. Phyllite.	Q. Quartzitic schist.	Gr. Granite dyke.	Gn. Gneiss.

Protarchæan and comparable to our Hebridean has yet been recognised.

4. Scandinavia

The most extensive exposures of the Archæan platform in Europe are to be found in Norway, Sweden, and Finland. The whole surface area of Finland, except where covered by drift and alluvium, consists of a complex of Archæan rocks with many intrusive masses of granite and porphyry. The greater part also of the Scandinavian peninsula is occupied by a similar complex, which, however, passes beneath a broad, central, and axial band of Cambrian, Ordovician, and Silurian deposits.

The natural eastern border of this band of Palæozoic sediments is obscured by very large tracts or sheets of overthrust and metamorphosed rocks which, according to Scandinavian geologists, include representatives both of the later Archæan and of the Palæozoic Systems. There is consequently a close correspondence

between the general structure of Scandinavia and that of Scotland, but the overthrust sheets in the former region are on a much larger scale, and appear to include a larger number of formations. Moreover there is this great difference between the two regions, that the forces producing the thrusts have acted from opposite directions, *i.e.* from the east in Scotland and from the west in Scandinavia; so that in the latter case the unaltered rocks are found in the areas which lie to the east of the overthrust tracts, *i.e.* in Sweden and Finmark.

The large areas occupied by Archæan rocks in the Fennoscandian region are partly shown in Fig. 10, which, however, does not include the more eastern districts. The Swedish and Finnish geologists³⁴ now recognise no less than four series or systems of pre-Cambrian rocks: (1) a fundamental complex which is comparable with the Hebridean of Scotland; (2) the *Kalevian*, which is a series of altered sediments and volcanic rocks; (3) the *Jatulian* (principally quartzites); (4) the *Jotnian* and *Sparagmite* sandstones, which seem to correspond with the Torridonian of Scotland.

The fundamental rocks are gneisses of several kinds, some being granitic gneisses which seem to be deformed and foliated granites; another type is the garnetiferous gneiss which is regarded as a combination of stratified gneiss (paragneiss) and gneissic granite (orthogneiss); while there are also banded grey gneisses (coarse and fine) and some red granitoid gneiss.

Above these gneisses, and apparently in stratigraphical sequence, is a sedimentary series which in Sweden is called the "Porphyry-Leptite" Group. This consists of mica-schists, green schists, leptites (= altered felspathic tuffs), schistose porphyrites (lavas), crystalline limestones, and iron ores; these rocks occur in regular bedded succession and alternation, but the bedding-planes are nearly always vertical, and the rocks themselves are crystalline. The series seems to be comparable with that of Loch Maree and Glenelg, but is on a much more extensive scale.

In parts of Lapland, Finland, and Olonetz (Russia), Dr. Sederholm has separated another series of metamorphosed sediments under the name of *Kalevian* (see Fig. 10), which he regards as newer than the Dalecarlian porphyrites and yet clearly older than the Jatulian. This series consists mainly of quartzites which are often micaceous, and pass into muscovite-schists; they also include bands of conglomerate and occasionally of talc-schist and dolomite. There are also intercalated sheets of metabasite (*i.e.* epidiorite).

This series has not yet been identified in Sweden, but Dr. Sederholm thinks it is included in the greatly folded and plicated complex of Northern Sweden, while in the south (Småland) there

Stanford's Geog. Estab^{ts}, London

Fig. 10.—GEOLOGICAL SKETCH-MAP OF FENNO-SCANDIA,
Showing the areas of Archæan and Palæozoic rocks.
(Based on a map by A. E. Törnebohm.)

are quartzitic schists on the border of a large area of granite which much resembles the post-Kalevian granites of Finland.

Here it may be remarked that all the areas occupied by these older Archæan rocks are invaded by large tracts of granite, most of which are older than the succeeding Jatulian and Jotnian Series.

The typical *Jatulian* is found in the east of Finland and in Olonetz. It rests with marked unconformity on the Kalevian, though itself consisting principally of white quartzites with bands of epidiorite. At or near the base are conglomerates containing rolled pebbles of granite, gneiss, and older vitreous quartzites. The Jatulian quartzites often show ripple-marks and desiccation-cracks. Above them are dolomitic limestones and shales (or slates), and in several places beds of anthracitic coal occur. The total thickness is about 2000 feet.

Whether there are any rocks of Jatulian age in Sweden is a matter of doubt. Sederholm regards the Dal formation, which occupies an area to the west of Lake Venern, as Jatulian, but his only reason is that the beds are strongly flexured and affected by pressure-metamorphism. Dr. Törnebohm dissents from this view and maintains that the Dalsland Series is Jotnian, the petrological resemblance being very close and the succession very clear, as given below :—

	Feet.
4. Schistose grits, grading into mica-schists	1300
3. White quartzite, with some beds of red slate	1500
2. Dark slates with intercalations of earthy limestone and red sandstone, and two or three sheets of schistose greenstone (= altered basic igneous rock)	2600
1. Reddish quartzitic sandstones, with beds of arkose and conglomerate at the base	650

About 6000

The typical *Jotnian* is a great red sandstone formation which has a great development in Central Sweden and Norway, extending in a nearly continuous band from the area near Lake Miosen to the extreme north-eastern end of Finmark, a distance of about 860 miles. It may be regarded as including the Sparagmite sandstone of Norway, though, where the two come together, the latter overlies the Jotnian with a certain amount of unconformity or contemporaneous erosion, but the time value of the break does not seem to be greater than that between the English Keuper and Bunter, so that they form parts of one and the same system. Each part of the series is over 2000 feet thick.

To the east of the overthrust areas the Jotnian sandstones are quite unaltered and lie in nearly horizontal sheets. At the base

there is a conglomerate, the pebbles in which are chiefly of quartz-porphry and orange-coloured quartzite. The mass of the formation consists of brownish-red or chocolate-coloured felspathic sandstones, in which false-bedding, ripple-marks, and desiccation-cracks are frequently observable. In the higher part thin layers of red shale occur, and there are also intercalated sheets of diabasic lava, some being intrusive sills and others extruded lava-flows which are sometimes amygdaloidal.

In Scandinavia these Jotnian and Sparagmite sandstones rest nearly everywhere on the rocks of the Protarchæan complex, and the unconformity between them is as striking and profound as that between the Torridonian and Hebridean of Scotland. In the latter country, as stated on p. 39, there is evidence of an intermediate formation having existed. In Scandinavia remnants of this (the Jatulian) still exist, but if it ever extended far toward the north it was destroyed before the formation of the Jotnian.

In the western metamorphosed tract the place of the Jotnian sandstones seems to be taken by the Åre schists; these are mainly quartzose flags and gneissic schists, including white mica-schists and brown garnetiferous schists. Högbom remarks that petrographically and tectonically the Åre schists very much resemble the Moine schists of Scotland. Both he and Törnebohm believe that they have originated from the Sparagmite sandstones, the latter becoming "transformed to mylonites, sericite schists, and white mica-schists within the western thrust areas and the crystallinity increasing from east to west." There is, however, a greater petrological difference between them than can be accounted for in this way, and there "must also have existed a primary difference between the eastern sparagmites and the western schists, a change of facies characterised partly by the entrance of basic igneous rocks into the western series, partly by the substitution of argillaceous and slaty sediments for the gritty sparagmites and conglomerates. The basic rocks just mentioned, which probably are to a great extent tufaceous (*i.e.* altered tuffs), repeatedly alternate with these argillaceous beds. Generally speaking, one can say that this change of facies goes on slowly from the east or south-east to the west or north-west."

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CHAPTER V

THE CAMBRIAN SYSTEM

A. NOMENCLATURE AND CLASSIFICATION

THE establishment of three separate systems among the Lower Palæozoic rocks was not accomplished without much controversy, for in early days only two were recognised, and both were made more comprehensive than they ought to have been.

The well-known name *Silurian* (from the British tribe of *Silures* who inhabited the western parts of Wales and its borders) was first introduced by Sir Roderick Murchison in 1835 to designate the series of rocks which he had studied in the land of the *Silures* (Shropshire, Herefordshire, and South Wales); he divided this system into an upper and a lower series.^{1 a}

In the meantime, between the years 1831 and 1835, Professor Sedgwick had worked out the complete succession of the Palæozoic rocks in North Wales, and in 1835 he proposed the name *Cambrian* for this series, which he divided into three portions, calling them Lower, Middle, and Upper Cambrian. For the beds which overlie this series in the Berwyn Mountains he adopted Murchison's name of *Silurian*.²

Sedgwick worked out the succession from below upwards, and Murchison worked from above downwards, and for a long time neither was aware of the fact that their systems overlapped each other. Murchison supposed that Sedgwick's Cambrian lay entirely below his *Silurian*, but when the fossils were collected and described, it was found that the Upper Cambrian was equivalent to the Lower *Silurian*, and this fact led to much subsequent controversy.

As Murchison became the Director-General of the Geological Survey, his nomenclature was naturally adopted by the surveyors, and as they found that his Lower *Silurian* had no natural base, group after group of Sedgwick's Cambrian was gradually absorbed

^a For references see end of the chapter.

into it, till the Lower Silurian came to include the whole of the rocks (below the Upper Silurian) in which any fossils had been found. This was obviously unfair and unscientific, since the so-called Lower Silurian was in reality a part of Sedgwick's Cambrian Series, the delineation of which by Sedgwick was accurate and complete. Still it was done, and the name Lower Silurian was generally adopted both in England and abroad.

The fact is, Sedgwick and Murchison both described more than one system of rocks, and each included two systems under one name. Sedgwick had clearly a right to call one system Cambrian and Murchison to call one Silurian, but there is really a third intermediate system, containing the second great fauna in the life-history of the globe, and to this neither geologist had a distinct claim. For this intermediate system Professor Lapworth proposed the name *Ordovician* (from the tribe of the Ordovices who inhabited North Wales), remarking,³ "That so long as present systems of nomenclature survive, nothing can disturb the application of the title Cambrian to the rocks of the 'Primordial Series,' and that of Silurian to the strata of the 'Third Fauna.' It is vastly different, however, with the intermediate series, which has been the object of incessant disputes from the day it was recognised until now." This proposal has met with very general acceptance, and has recently been adopted by the Geological Survey.

The following table shows the original arrangements of Sedgwick and Murchison, that formerly used by the Geological Survey, and lastly the one which is now in general use.

	Sedgwick, 1836.	Murchison, 1839-47.	Geological Survey.	Lapworth, (now used).	
Ludlow Beds	} Silurian	{ Upper Silurian	{ Upper Silurian	} Silurian.	
Wenlock Beds					
Llandovery Beds					
Bala Series	} Cambrian	{ Lower Silurian	{ Lower Silurian	} Ordovician.	
Llandilo Flags					
Llanvirn Series		{ Primordial Silurian		} Cambrian.	
Arenig Series					
Tremadoc Slates					
Lingula Flags		} Cambrian	} Cambrian		
Menevian					
Harlech Series		Cambrian	Cambrian		

Classification of the Cambrian System.—Since the time of Sedgwick and Murchison the Cambrian rocks have been investigated much more completely, and fossils have been found at various horizons down to the very base of the system. Fresh subdivisions have been established and new names introduced into the nomenclature. A *Menevian* Group has been separated from the *Lingula* flags, and

the Harlech Series was found to be divisible into two groups (the Caerfai and the Solva Beds). It has, moreover, been found that the whole succession is divisible into series which are characterised by special genera of trilobites, and that in many places a further subdivision can be made into zones based on the limitation of certain fossils (see p. 22). Thus the old lithological grouping has been modified to agree with the palæontological evidence, and the best modern arrangement of the rock-groups that compose the Cambrian system in England is as follows:—

Upper	{ Tremadoc Beds	= the <i>Bryograptus</i> fauna.
	{ Lingula Flags (in three stages)	= the <i>Olenus</i> fauna.
Middle	{ Menevian Beds	} = the <i>Paradoxides</i> fauna.
	{ Solva Beds	
Lower	= Caerfai Beds	= the <i>Olenellus</i> fauna.

B. LIFE OF THE PERIOD

Great interest attaches to the fossils which have been found in the Cambrian rocks, because, with the exception of the few organic remains mentioned on p. 61, they include the remains of the oldest animals hitherto discovered. At the same time the number of different classes of creatures which exist in the oldest Cambrian fauna make it certain that ancestors of these creatures must have existed in pre-Cambrian times, and there can be little doubt that some of them will sooner or later be discovered in the higher pre-Cambrian rocks.

The fossils which have been found in the Lower and Middle Cambrian of Wales and Shropshire are referable to the following groups—Porifera, Cystidea, Annelida, Brachiopoda, Gastropoda, and Crustacea; while representatives of Actinozoa, Crinoidea, Graptolitoida, and Lamellibranchia have also been obtained from rocks of the same age in North America. The very existence of so many different kinds of animals at this early period is a remarkable fact, and is a proof of the great gap which exists between the Cambrian and the pre-Cambrian rocks of Western Europe.

But although referred to many different classes, examination of the fossils themselves reveals the fact that most of them are represented by lowly and more or less generalised forms—that is, forms which combine in themselves characters that are now only found in two or more distinct families or orders of beings. Thus *Archæocyathus* and its allies have been classed by some with the Sponges and by others with Corals, and they are now regarded as a primitive family intermediate between Porifera and Actinozoa, and possibly representing the stock from which both these classes were derived.

The Cystidea again are placed by systematists at the bottom of the Echinoderina, and appear to represent an early stage in the evolution of the Echinoderm race.

Two of the Lower Cambrian Brachiopods (*Lingulella* and *Orbiculoidea*) are low forms of that class, and the others, *Obolella* and *Kutorgina*, were not much more highly organised. No Lamellibranchia have yet been found in the Lower Cambrian of Europe, but some small fossils found in North America are referred to this class. The Gastropoda are represented by the genus *Hyolithes* and its allies, which are usually referred to the Pteropods, though their real affinities are very doubtful. More typical Gastropods appear in the Lower Cambrian of America and in the Middle Cambrian of Scotland.

Crustacea are represented by the Entomostraca and Trilobita. The former are true Crustacea of low organisation; the latter exhibit a curious mingling of characters, which have led some authors to exclude them from the Crustacea, but Professor Beecher^a remarks that Trilobites show the clearest evidence of primitive Crustacean affinities.

In the Middle and Upper Cambrian Hydrozoa (Graptolites), Crinoid and Asteroid Echinoderms, Phyllocarid Crustacea, a few Lamellibranchs and Gastropods, with some Nautiloid Cephalopoda make their appearance. The occurrence of Cephalopoda, the highest of the Molluscan classes, suggests that the evolution and development of marine Mollusca must have been especially rapid during this early period of the earth's history, or else that their ancestors existed somewhere long before Cambrian times.

The following are the principal characteristic species of the several faunas which have been recognised in the Cambrian System.

Lower Cambrian (Olenellus Fauna)

<i>Ostracoda.</i>	<i>Leperditia cambrensis.</i>
<i>Annelida.</i>	<i>Serpulites fistula</i> , <i>Scolithus linearis.</i>
<i>Trilobita.</i>	<i>Olenellus Callavei</i> , <i>O. Lapworthi</i> , <i>O. intermedius</i> , <i>Olenelloides armatus.</i>
<i>Brachiopoda.</i>	<i>Lingulella primæva</i> , <i>Orbiculoidea caerfaensis</i> , <i>Kutorgina cingulata</i> , <i>Obolella Salteri</i> , <i>Acrotreta Sabrinæ.</i>
<i>Gastropoda.</i>	<i>Hyolithes princeps</i> , <i>Orthotheca Geeri</i> , <i>Stenotheca rugosa</i> , <i>Coleoloides typicalis</i> , <i>Salterella pulchella</i> , <i>S. Maccullochi.</i>

Middle Cambrian (Paradoxides Fauna)

<i>Porifera.</i>	<i>Protospongia fenestrata</i> (S. and M.), <i>P. major</i> (S.). ^a
<i>Cystidea.</i>	<i>Protocystis menevensis</i> (M.).

^a S. indicates occurrence in Solva Beds, M. in Menevian.

Fig. 11.—GROUP OF LOWER CAMBRIAN FOSSILS.

1. *a*, *b*. *Obolella Groomi* (enlarged). *c*. *Olenellus Callavei* (reduced).
 2. The same (shell highly enlarged). *d*. *Kutorgina cingulata* (enlarged).

Fig. 12.—GROUP OF IRISH CAMBRIAN FOSSILS.

- a*. *Oldhamia antiqua*. *c*. *Histioderma hibernicum*.
b. *Oldhamia radiata*. *d*. *Arenicolites didyma*.

- Trilobita.* Paradoxides Harknessi (S.), P. aurora (S.), P. Davidis (M.),
Erinnys venulosa (M.), Conocoryphe Lyelli (S.), C.
solvensis (S.), Plutonia Sedgwicki (S.), Solenopleuro
variolaris (M.), Agnostus cambrensis (S.), Microdiscus
sculptus (S.), M. punctatus (M.).
- Brachiopoda.* Lingulella ferruginea (S. and M.), Obolella sagittalis,
(S. and M.), Orbiculoides pileolus (S. and M.), Orthis
Hicksi (M.).

Fig. 13.—GROUP OF LOWER CAMBRIAN FOSSILS.

a. Conocoryphe Lyelli.	d. Hyolithes corrugatus.	m. Agnostus Cambrensis
b. Microdiscus sculptus.	e. Lingulella ferruginea.	(nat. size and enlarged).
c. Paradoxides Davidis.	f. Protospongia fenestella.	n. Orbiculoides pileolus
		(much enlarged).

Gastropoda. Hyolithes antiqua (S.), H. corrugata (M.), Cyrtotheca
hamula (M.).

Upper Cambrian (Lingula Flags)

- Annelida.* Cruziana semiplicata, Oldhamia antiqua, O. radiata,
Histioderma hibernica.
- Trilobita.* Olenus cataractes, O. micrurus, Peltura scarabaeoides,
Parabolina spinulosa, Conocoryphe bucephala, Agnostus
pisiformis, A. trisectus.
- Phyllocarida.* Hymenocaris vermicauda.

<i>Brachiopoda.</i>	<i>Lingulella Davisii</i> , <i>Orthis lenticularis</i> (and in Tremadoc).
<i>Gastropoda.</i>	<i>Bellerophon cambrensis</i> .

Upper Cambrian (Tremadoc)

<i>Hydrozoa.</i>	<i>Dictyograptus socialis</i> (= <i>Dictyonema</i>), <i>Bryograptus Callavei</i> , B. Kjerulfi.
<i>Echinoderma.</i>	<i>Dendrocrinus cambrensis</i> , <i>Palæasterina ramseyensis</i> .
<i>Trilobita.</i>	<i>Asaphellus Homfrayi</i> , <i>Ogygia scutatrix</i> , <i>Niobe Homfrayi</i> , <i>Angelina Sedgwicki</i> , <i>Sphærophthalmus alatus</i> , <i>Peltura punctata</i> .
<i>Brachiopoda.</i>	<i>Lingulella lepis</i> , <i>Obolella Belti</i> , <i>O. sabrinae</i> , <i>Orthis lenticularis</i> , and <i>O. Carausi</i> , <i>Orthisina festinata</i> .
<i>Lamellibranchia.</i>	<i>Palæarca Hopkinsoni</i> , <i>Glyptarca primæva</i> , <i>Ctenodonta menapiensis</i> .
<i>Gastropoda.</i>	<i>Hyolithes cuspidatus</i> , <i>Conularia Homfrayi</i> , <i>Bellerophon arfonensis</i> .
<i>Cephalopoda.</i>	<i>Orthoceras sericeum</i> , <i>O. mendax</i> , <i>Cyrtoceras præcox</i> .

C. BRITISH CAMBRIAN ROCKS

Range and Relation to Rocks below.—Cambrian rocks rise to the surface in several parts of England and Wales, as well as in Ireland and Scotland, but they nowhere occupy any large tract of country and they exhibit several very different facies, so that it is with some difficulty that the component members of these isolated exposures can be compared with one another.

In Wales, the typical area, there are four districts where Cambrian strata emerge from beneath the overlying Ordovician, namely in Pembrokeshire, Merionethshire, Carnarvonshire, and Anglesey. In England there are six outcrops, but all are small; these are (1) The Malvern Hills, (2) The Wrekin area in Shropshire, (3) The Lickey (N. Worcestershire), (4) near Nuneaton in Warwickshire, (5) The Lake District, and (6) The Isle of Man.

In Ireland rocks which are believed to be of Upper Cambrian age occur in Wicklow and Wexford, but they contain very few organic remains, and none of the Welsh Cambrian fossils have yet been found in them.

In Scotland they have only yet been recognised in the extreme north-west (Sutherland, Ross, and Skye), where they consist mainly of limestones, and thus exhibit a very different facies from those occurring in the more southern areas.

Wherever the base of the Lower Cambrian Series is exposed, it is seen to rest unconformably upon an eroded and planed down surface of the Archæan rocks. This is conspicuously the case in Scotland and in most of the English localities, but the base is not exposed in Cumberland, the Isle of Man, nor in Ireland.

Fig. 14.—GROUP OF LINGULA FLAG FOSSILS.

- a. *Cruziana semiplicate*.
 b. *Dictyonema sociale*.
 c. *Lingulella Davisi*.
 d. *Olenus micrurus*.
 e. *Agnostus pisiformis*.

- f. *Hymenocaris vermicanda*.
 g. *Spharopthalmus alatus*.
 h. *Orthis lenticularis*.
 i. *Conocoryphe bucephala*.
 n. *Parabolina spinulosa*.

Fig. 15.—GROUP OF TREMADOC FOSSILS.

- a.* Asaphus Homfrayi.
b. Angelina Sedgwicki.
c. Conularia Homfrayi.
d. Niobe Homfrayi.
e. Bellerophon arfonensis.

- f.* Palæarca Hopkinsoni.
g. Orthis Carausi.
h. Orthoceras mendax.
m. Bryograptus Kjerulfi.
n. Part of same magnified.

1. *The Cambrian of Wales*

Though the exposed tracts of Cambrian rocks in Wales are rather far apart it will be convenient to treat the whole as one area, because the several tracts are doubtless portions of one continuous subterranean mass, and because in process of time the same stages and subdivisions will probably be recognised in all the separate districts.

Both in this and subsequent chapters I shall assume that the student possesses a copy of the cheap general Geological Map of the British Islands, published by the Geological Survey (see p. 27), so that he may see at a glance the relative positions of the areas described. The descriptions here given will in some cases be illustrated by special maps, and for other parts of the country the reader can obtain the Index maps of England and Southern Scotland, which are published in sheets (see p. 28).

The Cambrian rocks of North Wales were first described and classified by Professor Sedgwick, and the lowest series of beds, in which he found no fossils, were termed by him the *Harlech grits*. The beds in Pembrokeshire were first properly identified and described by Dr. H. Hicks,⁵ who obtained fossils from the equivalents of the *Harlech grits*, and was thus led to divide the series into two groups which he named respectively the Caerfai Beds and Solva Beds. He was also the first to separate the Menevian from the Lingula flags, and to make a detailed map of the St. David's area which is reproduced in Fig. 16.

We shall now indicate the representatives of the three divisions of the Cambrian (Lower, Middle, and Upper) in each of the separate areas, so far as it is possible to do so.

Olenellian or Lower Cambrian.—In Pembrokeshire this series, named Caerfai Beds by Dr. Hicks, is estimated to have a thickness of about 1600 feet, and to consist of the following sets of beds in descending order:—

	Feet.
Purple sandstones with Annelid tracks	1000
Red shales with <i>Lingulella primæva</i> , <i>Discina</i> , and fragments of <i>Olenellus</i>	50
Flaggy sandstones with Annelid markings	460
Conglomerates	60 to 150

About 1600

The basal bed of this series is the Cambrian conglomerate so frequently mentioned in the preceding chapter. Near St. David's it is about 60 feet thick, and consists of well-rounded pebbles set in a matrix which is a mixture of sandy and ashy materials;

sometimes the ashy element appears to predominate, sometimes it is a true arkose, consisting of quartz-sand and decomposed felspar. The pebbles vary in size, ranging up to a foot in diameter; they consist principally of a reddish quartzite and of quartz, but include some of quartz-felsite, porcellanite, schist, and granitoid rock, all derived from the underlying pre-Cambrian rocks.

In Merioneth the equivalents of the Caerfai Series are to be found in the central parts of the Harlech dome (see Fig. 19). The

GEOLOGICAL MAP OF THE COUNTRY NEAR ST DAVID'S

Fig. 16.—MAP OF PART OF SOUTH WALES (after Hicks).

great Harlech Series, believed to be from 5000 to 6000 feet thick, was not subdivided by Sir A. Ramsay and the officers of the Geological Survey, but quite recently Professor Lapworth and Dr. T. S. Wilson have mapped a large part of the district and have determined the sequence of the beds. Their detailed descriptions have not yet been published, but they have allowed a summary of the succession to be printed in a paper by Mr. A. R. Andrews,⁶ and from this the following brief account is gleaned.

The lowest beds occupy the coast between Egryn Abbey and Llanfair and extend eastward to the Rhinog Mountains. The red felspathic grits of Dolwen are probably not far from the base of the

series, which, however, is not exposed. Above them are blue and purple slates and grits (the *Cefu Slate Group*) of which there may be 1000 feet. These are succeeded by the *Rhinog grits*, which have a thickness of about 2500 feet. These two groups may be regarded as representing the Lower Cambrian.

Passing under the great mountain mass of the Snowdon range, the Harlech Series again emerges and occupies a considerable area in Carnarvonshire from the coast near Clynnog to Penrhyn and Llanllechid on the north-west, lying on both sides of the axial ridge of Archæan rocks. The basal beds are grits and conglomerates, which contain pebbles of granite, quartz-felsite, and porcellanite derived from the pre-Cambrian rocks described in the preceding chapter. These are succeeded by a thick series of purple and green slates, some of which are worked at the celebrated slate quarries of Penrhyn and Llanberis; above these again are coarse grits and sandstones. The total thickness on the eastern side of the anticline near Llanberis is estimated at about 3000 feet.

The beds exposed in and near the Penrhyn slate quarries were described by Professor T. M'K. Hughes in 1889, from whose paper the following condensed account of the succession is taken:—

	Lingula flags with <i>L. Davisii</i> .	Feet.
Middle.	6. Coarse grits and sandstones of Broullwyd	! 500
	5. Purple and bluish-green slates, yielding <i>Conocoryphe viola</i> in the upper part	1500
? Lower.	4. Band of fine red grit (15 feet).	
	3. Purple and veined slates (quarried)	540
	2. Green sandy slates	300
	1. Grits, slates, and basal conglomerate	! 300
		<hr/> 3140

Of these beds 1 to 4 may represent the Caerfai Series, but as no fossils have yet been found in them correlation is uncertain.

Paradoxidian or Middle Cambrian.—This series is distinguished by the presence of several species of the Trilobite genus *Paradoxides*. In Pembrokeshire it was divided by Dr. Hicks into two stages, the *Solva Group* and the *Menevian Group*, *Menevia* being the ancient name of St. David's. He also recognised the following subdivisions or zones:—

		Feet.
Menevian.	{ Sandstones and shales, with <i>Orthis Hicksi</i>	100
	{ Flags and shales, with <i>Paradoxides Davidis</i>	350
	{ Flags and shales, with <i>Paradoxides Hicksi</i>	300
Solva.	{ Grey flagstones and grits with <i>Paradoxides aurora</i>	150
	{ Red, purple, and grey sandstones and slates with <i>Paradoxides solvensis</i>	1500
	{ Yellowish sandstones and grey flags with <i>Paradoxides Harknessi</i>	150
		<hr/> 2550

The lowest beds are yellowish sandstones with some pebble beds, and above these are grey flags which have yielded a number of fossils, including *Paradoxides Harknessi*, *Plutonina Sedgwicki*, *Microdiscus sculptus*, *Conocoryphe Lyelli*, *Agnostus cambrensis*, and *Hyolithes antiqua*. The central group is of great thickness and yields fragments of fossils at different horizons, but it was only near the top that Dr. Hicks found *Paradoxides solvensis* and *Conocoryphe solvensis* with some other fossils. The upper beds contain other species of *Paradoxides* and *Conocoryphe*, while *Agnostus cambrensis* and *Lingulella ferruginea* occur in all three groups.

The Menevian Group consists mainly of dark-grey flagstones and black shales, and from the middle zone Dr. Hicks obtained 28 species of fossils belonging to the Trilobite genera *Paradoxides*, *Conocoryphe*, *Microdiscus*, *Anopolenus*, *Arionellus*, *Erinnys*, *Agnostus*, and *Holocephalina* with Brachiopods of the genera *Lingulella*, *Discina*, *Obolella*, and *Orthis*; and some Gasteropod Mollusca of the genera *Hyolithes*, *Stenotheca*, and *Cyrtotheca*.

In Merioneth, according to Messrs. Lapworth and Wilson, the series is represented by the following succession of beds:—

	Feet.
<i>Clogau Beds</i> (=Menevian), black shales and slates	250
<i>Gamlan Shales</i> , a series of grey and greenish shales and flags, with beds of grit which thicken eastward	1000
<i>Barmouth Grits</i> , thick felspathic grits with some bands of pebbles	600
<i>Hafotty or Manganese Shales</i> , grey and green shales and flags with grits which thicken eastward	1000

About 2850

No fossils have yet been found in the great series of greenish-grey shales and grits which seem to be the equivalents of the Solva stage, but the Menevian has yielded 19 species, including 5 species of *Agnostus*, 2 of *Anopolenus*, 3 of *Paradoxides* with *Microdiscus punctatus*, *Lingulella ferruginea*, and *Hyolithes corrugata*.

In Carnarvonshire the Solva Group is evidently represented by the upper green and purple slates of Llanberis and of Penrhyn

Fig. 17.--DIAGRAM SECTION ACROSS CARNARVONSHIRE (by Professor T. M. Hughes). $\frac{1}{2}$ Distance 11 miles.

d. Bala and Llandilo Beds.
c. Arenig Series, with pisol-
ironstone (?) at base.

b. Lingula flags.
*a*². Llanberis slates.
a. Cambrian grits.

F. Faults.
D. Dykes of igneous rock.
x. Broken ground.

j. h. Grey shales
l. g. c. Sills of igneous rock
f. d. Black shales
c. b. Hollybush sandstone

- l. Trias.
- k. Llandovery Beds.
- d. Pre-Cambrian gneiss.
- FF. Faults.

in which *Conocoryphe viola* was found (see p. 81), but nothing like the black Menevian slates and mudstones appears to exist in that area. Whether originally present and now cut out by faults, or whether they were eroded before the deposition of the Lingula flags, is a question for future investigation. Mr. Fearnside is of opinion that there are local unconformities at the base of the Upper Cambrian, and that this absence of the Menevian in Carnarvonshire is probably due to erosion.

Olenian or Upper Cambrian.—As already stated this consists of the groups known as the Lingula flags and the Tremadoc Beds, and as in the case of the underlying Middle and Lower Cambrians their thickness is greatest in Merioneth, which seems to have been near the centre of the Welsh basin of deposition in Cambrian time.

In Pembrokeshire the total thickness of this division is not half that which it attains in Merioneth, though some of the same zones or subdivisions seem to be represented. The area has not yet been resurveyed by the Geological Survey and Dr. Hicks' account of them is still the best available, but Mr. J. F. N. Green considers it probable that there is a break or non-sequence between the Lingula flags and the Tremadoc.⁷ The succession is as follows :—

		Fet.
Tremadoc Beds.	Black flagstones and slates with <i>Nesacretus Ramseyensis</i> , <i>Niobe Homfrayi</i> , and Lamellibranchs	1000
	Upper—Fine grey slates without fossils	300
Lingula Flags.	Middle—Hard grey micaceous flags with <i>Lingulella Davisi</i> in abundance	1000
	Lower—Grey flagstones and black slates without fossils	700

These beds appear to form a continuous band along the northern side of the Cambrian area from Whitesand Bay to the country south of Llanvirm and beyond Crugglas (see Fig. 16); east of St. David's they are seen in Solva Harbour, and inland they spread eastward round another tract of Lower and Middle Cambrian rocks of which little is yet known.

Another small tract of Lower Tremadoc Beds is found round Tremanhire, a place about 4 miles east of St. David's; they are brought in above the Lingula flags by a synclinal flexure, and have yielded many of the same fossils as in Ramsey Island.

Tremadoc slates have also been found to the south of Caernarthen by the Misses Crossfield and Skeat, and their presence there is interesting as it was unsuspected. They yielded *Orthoceras sericeum* and two new species of Trilobites, *Peltura punctata* and *Ogygia*

Harlech dome (see Fig. 19). They are well exposed near Dolgelly and Ffestiniog and were studied in 1867 by Mr. Belt, who subdivided them into three groups, each characterised by a certain assemblage of Trilobites and other fossils. More recently they have been examined by Professor Lapworth and Dr. Wilson (*op. cit.*), who appear to accept and confirm Belt's main divisions, which are as follows with thicknesses corrected by the later estimates.

Dolgelly	{ Soft black shales with <i>Peltura scaraboides</i>	. . .	Feet.
Beds	{ Hard blue slates with <i>Parabolina spinulosa</i>	. . .	300
Ffestiniog	{ Bluish-grey flags with <i>Olenus micrurus</i>	. . .	50
Beds	{ Grey micaceous flags with <i>Hymenocaris</i>	. . .	3000
Maentwrog	{ Black slates and flags with <i>Olenus gibbosus</i>	. . .	1600
Beds	{ Dark-grey flags and shales with <i>O. cataractes</i>	. . .	1000

About 6250

The lower portion of the Maentwrog Beds has been termed the *Vigra Beds* by Messrs. Lapworth and Wilson, and the higher

FIG. 20.—SECTION ACROSS THE PENRHYN PROMONTORY (after Salter).

12, 13. Llanvirnian.	2 to 4. Lower Tremadoc.
11. Arenig Grit.	1 and 1a. Lingula flags.
5 to 10. Upper Tremadoc.	g. Intrusive dyke of igneous rock.

There is probably a fault below the letter F.

portion the *Pen Rhos Beds*. The former contain beds of fine siliceous grit from 2 to 3 feet thick, while in the latter such grits are only from $\frac{1}{2}$ to 2 inches thick. Two species of *Olenus* and *Agnostus pisiformis* are the characteristic fossils.

The Ffestiniog Group is a thick mass of flagstones with only a few bands of black shale; they are usually hard and consequently form higher ground than the underlying shales. The most abundant fossil throughout is *Lingulella Davisii*.

The Dolgelly Group consists of soft blue and black shales, which appear to have been formed in much deeper water and though only 600 feet probably represent as long a period of time as the whole of the Ffestiniog Beds. They resemble the Alum shales of Sweden.

The best section of the Tremadoc slates in North Wales is in the cliffs of the Penrhyn promontory south-east of Tremadoc in Merioneth. According to Mr. Salter⁸ the succession which can here be seen is as follows :—

Arenig	{	12. Black slates with iron stains.
		11. Garth Hill grit.
		10. Hard bluish flags with many fossils, <i>Angelina Sedgwicki</i> ,
<i>Asaphellus Homfrayi</i> , <i>Ogygia scutatrix</i> , etc.
Upper Tremadoc	{	9. Soft sandy shales with <i>Shumardia</i> .
		8, 7. Alternating beds of hard bluish slate and black pencil slate.
		6, 5. Thick beds of pencil slate, with some hard sandy layers,
<i>Asaphellus Homfrayi</i> .
Lower Tremadoc	{	4. Hard bluish slaty rock in massive beds.
		3, 2. Dark iron-stained slates, with <i>Psilococephalus innotatus</i> ,
<i>Niobe Homfrayi</i> , <i>Dictyograptus socialis</i> .
		1. Lingula flags—Black slates with <i>Olenus</i> .

Mr. Fearnside has recently described a similar succession near Tremadoc on the east side of the Lleyn peninsula, where the Upper Tremadoc Beds (440 feet thick) yield species of *Asaphellus*, *Angelina Shumardia*, *Symphysurus*, and *Dikellocephalus*.⁹

The Tremadoc Beds do not form a continuous band round the Lingula flags of Merioneth, for in certain places they seem to disappear beneath the base of the Arenig Series (Ordovician); it is now believed that there is an actual unconformity between the two series and that the Arenig often completely oversteps the whole of the Tremadoc Group so as to rest on Lingula flags.

In Carnarvonshire the thickness of the Lingula flags is much less, but near Llanberis and Nant Ffrancon they are apparently from 2000 to 2500 feet thick. On each side of Llyn Peris the nearly vertical Harlech grits are succeeded by dark slates which represent the Maentwrog Beds, with a thickness of about 1000 feet, and these are followed at the eastern end of the lake by hard quartzose grits (?Ffestiniog beds), which are estimated by Ramsay to be about 1300 feet thick.¹⁰ These beds are traceable northward through Elidyr-fawr, and a good section is exposed in the southern cliffs of Marchlyn-mawr, where Ramsay found *Olenus micrurus* and *Lingulella Davisii* in certain grey and brown grits. It is noticeable that some of these grits are of coarse grain, and occasionally conglomeratic, thus differing from the finer-grained flagstones of Merioneth. The Upper Lingula flags or Dolgelly Beds have not yet been identified in Carnarvon owing to the rarity of fossils, but are probably represented by a part of the overlying slates.

On the western side of the Llanberis anticline the thickness of the Cambrian Series seems to be still further reduced, and when they again emerge on the eastern flank of the Bangor-Carnarvon ridge there are only slates overlying the basal grits and conglomerates.

Professor Hughes¹¹ has traced these basal beds along the eastern flank of the pre-Cambrian ridge all the way from Twt Hill near

Carnarvon to Garth Point near Bangor. The pebbles vary according to the rocks on which the conglomerate locally rests; near Carnarvon they are chiefly quartz, near Llanddeiniolen and near Bangor they include pebbles of quartzite, andesite, felsite, and quartz.

Sir A. Ramsay was of opinion that the whole of the Lingula flags had thinned out near Bangor, that the grits were of Harlech age and were overlain unconformably by Arenig shales. This, however, is not the generally accepted view, for there is no evidence of such unconformity, and if the diminution of thickness is due to thinning out toward a shore line we should expect the lower beds to thin out and disappear before the upper beds. The facts may be explained as a simple case of overlap, and we may suppose that the whole of the Harlech Series (*i.e.* Lower and Middle Cambrian) has thinned out with probably some of the Lingula slates (Maentwrog Beds), and that the lowest Cambrians between Llanddeiniolen and Bangor represent the Lingula grits of Elidyr-fawr and Marchlyn-mawr. They may, however, be of still later date.

Whether Tremadoc Beds exist to the north-west of Snowdon has not yet been ascertained because of the scarcity of fossils in the mass of dark slates which intervenes between the Lingula grits and the Arenig grits.

2. *Midland Counties*

Cambrian rocks are brought to the surface in four distinct and isolated areas in the Midlands, viz. (1) Malvern Hills, (2) The Wrekin (Shropshire), (3) the Lower Lickey Hill (Worcestershire), and (4) Nuneaton (Warwickshire). In lithological characters, and to some extent also in their fossil contents, these Midland rocks differ very much from the typical Cambrian of Wales, and according to Professor Lapworth¹² they approximate more closely to the Cambrian of Scotland and of the continent of Europe. The total thickness of the system is very much less in the Midlands than in Wales, and though it is believed that in the western areas the succession is incomplete, it appears to be unbroken near Nuneaton, where the thickness of the exposed beds is only about 2200 feet, and if 800 feet are added for the concealed upper beds, the total is then only 3000. The whole system is divisible into a lower arenaceous division, comparable to the Caerfai and Solva Beds of South Wales, and an upper shaly division, representing the Lingula flags and the Tremadoc Beds.

The Arenaceous Division.—At the south-west end of the Malvern Hills the Archæan schists are bordered by beds of quartzite

and of greenish flaggy micaceous sandstone which have been called the *Hollybush sandstone*. In these beds Dr. T. T. Groom has recognised the following descending succession :—¹³

2. *Hollybush Sandstone*, consisting of :

b. Massive glauconitic sandstones, from 550 to 700 feet thick, with several species of *Hyolithes* (including *H. fistula*), *Kutorgina cingulata* var *Phillipsi*, etc.

a. Shaly sandstone, with calcareous bands and seams of quartzite, not less than 220 feet, with *Kut. Phillipsi*, *Obolella* sp., *Linnarssonina sagittalis*, *Hyolithes* sp.

1. *Hollybush Quartzite*.—Quartzites and conglomerates of unknown thickness, with *Kutorgina*, *Obolella*, and *Hyolithes*.

The conglomerates in the quartzite contain pebbles of metamorphic quartzite, rhyolite, andesite, and red granophyre, and the mass was supposed to rest unconformably on the pre-Cambrian rocks. It is probable that such was their relation, but Professor Groom believes the present junction planes to be faults, and thinks that the quartzite may have been several hundred feet thick, though only 50 or 60 feet of it can now be seen.

In Shropshire the Wrekin ridge, as well as the Uriconian rocks of the Caradoc and Cardington Hills, are flanked on their eastern sides by a series of Cambrian rocks, the lowest being a hard quartzite like that of Malvern (see map, Fig. 21, here reproduced by permission of Professor C. Lapworth); but its base is seen to rest directly and unconformably on the Archæan rocks, and it contains pebbles of rhyolite, tuff, etc., derived from them.

This quartzite is about 300 feet thick, and is succeeded by a series of sandstones, limestones, grits, and shales which are generally known as the Comley sandstone, though they include representatives of two faunal divisions. This series is supposed to be about 500 feet thick. Its true age was first recognised by Dr. C. Callaway in 1877, and the *Olenellus* fauna was first discovered in it by Professor C. Lapworth in 1888. Still later exploration by Mr. G. S. Cobbold has resulted in the discovery of more fossils and has shown that the succession of fossiliferous beds at Comley is as follows :—¹⁴

Paradoxides Beds	{ Flaggy shales and grits. Coarse calcareous grit with fragments of sandstone and limestone derived from beds below.
Olenellus Beds	{ Black limestone with phosphatic nodules (1 foot). Grey limestones with black phosphatic nodules (4 feet). Purplish-red sandy limestone with <i>Olenellus</i> . Greenish felspathic sandstones.

Fig. 21.—GEOLOGICAL MAP OF PART OF SHROPSHIRE (by Professor C. Lapworth).

The red limestone contains *Olenellus Cullavei*, *Microdiscus helena* with new species of *Ptychoparia* and *Micmacchia*, and *Kutorgina cingulata*. The grey limestones have yielded new species of *Protolemis*, *Microdiscus*, *Anomocare*, and *Mohicana*, with some *Brachiopoda*. The black limestone contains *Hyolites*, *Satterella*, and *Brachiopoda*.

The overlying conglomeratic grit with its derived fragments indicates a local break with erosion of the beds below so that it may be inferred that the latter are only a part of the series originally deposited. This upper grit has yielded three species of *Paradoxides* (*P. Groomi*, *P. rugulosus*, and *P. cf. Davidis*).

In the Lickey district there is an exposure of quartzite which is almost certainly of Lower Cambrian age, though no fossils except worm-burrows have yet been found in it. It consists of flaggy

Fig. 22.—SECTION FROM NUNEATON TO CALDECOTE HILL (Lapworth).

f. Keuper marls.
d. Coal-measures.
a. Oldbury shales.
a3. Purley shales.

a2. Hyolites Beds.
a1. Cambrian quartzite.
A. Caldecote volcanic rocks.
Diorite dykes shown in black.

quartzites, with intercalated purple shales like those next described.

Near Nuneaton there is a remarkable tract of Cambrian rocks which before the discovery of fossils was supposed to be of Carboniferous age. It is about 9 miles in length, with a width of a mile where broadest, and the structure of the district is shown in the section drawn by Professor Lapworth (Fig. 22). The arenaceous division has been called the *Hartshill quartzite*, and is about 600 feet thick. The lower part consists of alternating beds of siliceous grit and purple or grey shale, the grits consisting of sand set in a chalcedonic cement, and forming a very hard rock which has usually a pale pink colour. No fossils have yet been found in them. The middle portion consists of thick beds of quartzitic grit with very little shale, and has not yielded any fossils. The Upper or Camp Hill Group is a much more varied set of beds, consisting at the base of thin-bedded glauconitic grits, followed by sandy micaceous shales about 50 feet thick, in which are two notable beds, one a pebble bed or conglomerate, and the other a bed of red limestone about 2 feet thick. The highest member is a mass of

purple false-bedded quartzitic sandstone containing many grains of glauconite and about 50 feet thick.

The limestone and associated red shales have yielded several species of *Hyolithes* and of *Orthotheca*, with *Stenotheca rugosa*, *Coleoloides typicalis*, *Kutorgina cingulata* and *Iphidea labradorica*, and *Orthisina transversa*. The facies of the fauna is that of the Lower Cambrian or *Olenellus* zone, though no trilobites have yet been found.

The Shaly Division (Upper Cambrian).—In the Malvern area this is over 2000 feet thick, and is divisible into two parts. The lower 800 feet are black shales with bands of basaltic lava which have generally been regarded as contemporaneous lava-flows, but which Dr. Groom finds to be intrusive sills. These shales have yielded *Peltura scarabæoides*, *Ctenopyge bisulcata*, *Agnostus trisectus*, *Sphærophthalmus alatus*, etc.—species which are characteristic of the Lower Dolgelly Beds of North Wales. The upper part of the Malvern shales is composed of bluish or yellowish-grey shales, with many intrusive sills of basalt and diabase. Dr. Groom¹⁵ found them to be of much greater thickness than was previously supposed, and from his section, reproduced in Fig. 18, it will be seen that they are at least 1300 feet thick. Their highest beds contain *Dictyograptus socialis*, *Agnostus dux*, *Cheirurus Frederici*, *Acrotreta Sabrina*, with species of *Asaphus* and *Olenus*; most probably they are of Lower Tremadoc age. No representatives of the Menevian, Maentwrog, or Ffestiniog beds have yet been recognised, but the boundary between the Hollybush sandstone and the Malvern shales seems to be a faulted one, so that beds of intermediate age may be faulted out.

In Shropshire the *Shinerton shales* occupy a tract two miles broad in the valley of the Severn by Shinerton and Cressage, and they extend both to the north-east and south-west (see map, Fig. 21). They also occur at Pedwardine, and again in a long narrow strip on the west side of the Longmynd, where they underlie the Arenig Beds of the Stiper stones. Their true age was first made known by Dr. Ch. Callaway,¹⁶ who discovered in them fossils of Upper Cambrian types. They are soft, fissile, micaceous shales of a dark-blue colour, weathering to olive-green and yellow. Their base is not seen, and their junction with the Comley sandstone appears to be a fault, so that here, as at Malvern, the central part of the Cambrian System seems to be missing. The lowest beds contain *Dictyonema*. The highest beds are more fossiliferous and have yielded many trilobites, including *Eulonia monile*, *Olenus Salteri*, *Asaphellus Homfrayi*, *A. Crofti*, and *Shumardia salopiensis*, with the Cystidean *Macrocystella Marie*.

The total thickness is estimated at about 1500 feet and the beds are clearly of Tremadoc age.

Passing again to Nuneaton, where the Hartshill quartzite is succeeded by the Stockingford shales, we have what appears to be a complete succession without break or faulting. Professor Lapworth has divided the shaly series into three groups, of which the following is a brief description, taking them in descending order:—

Upper or Merevale Shales.—Only seen near Merevale, and consisting of greenish-grey shales in which *Dictyograptus* is abundant. The thickness exposed may be 200 feet.

Middle or Oldbury Shales.—Black shales, with some bands of grey shale; in highest beds are *Sphærophthalmus alatus* and *Ctenopyge pecten*; in the lower *Agnostus pisiformis*, *Leptoplastus Salteri*, *Beyrichia Angelini*, and a *Lingulella*. Thickness probably 800 feet.

Lower or Purley Shales.—Reddish-purple mudstones and shales, with some green and grey bands, containing minute *Lingulella*, *Obolella sagittalis*, *Acrothele granulata*, and a *Conocoryphe*. Thickness about 600 feet.

The fauna of the Purley shales is comparable with that of the *Conocoryphe exulans* zone of Sweden, which belongs to the *Paradoxides* division and is homotaxial with our Menevian Series. The black Oldbury shales are comparable with the black shales of Malvern and the Lower Dolgelly Beds. The Merevale shales appear to represent the lowest part of the Shineton shales and of the Malvern grey shale. No horizon comparable with the mass of *Lingula* flags has been recognised, but this may be due to the scarcity of fossils in the lower part of the Oldbury shales.

3. Lake District and the Isle of Man

In the northern part of the Lake District around Skiddaw Mountain, Derwent, and Crummock Waters there is a great thickness of dark-coloured slates, with bands of hard grit and occasional beds of conglomerate. To these beds Sedgwick gave the name of *Skiddaw slates*; the higher portion of them is of Ordovician (Arenig) age, but the lower part is Cambrian (Tremadoc and *Lingula* flags). The Cambrian age of this portion was suspected by Sedgwick and maintained by Clifton Ward, but not until 1894 was this view confirmed by good palæontological evidence.¹⁷

Mr. Ward took a certain band of grit occurring north of Skiddaw as the base of the Arenig Series and identified with it certain flaggy grits near Buttermere, but this has not been confirmed and the boundary line between Cambrian and Ordovician has not yet been

determined, the difficulty being that the rocks are so much folded, contorted, and faulted that it is almost impossible to trace particular beds in the mass of slates. Few fossils except graptolites have been found, and these occur in definite bands of a more earthy kind of slate than the rest, so that, as Dr. Marr observes, "whether these beds are of the same age as the black glossy unfossiliferous slates, or whether they are newer beds folded as synclines among these slates, yet remains to be ascertained."

The only locality indeed where graptolites of Tremadoc species have yet been found is Barth near Keswick, where the following species were obtained by Miss G. L. Elles¹⁸ in 1898—*Bryograptus Kjerulfi* (see Fig. 15 m), *B. ramosus*, *B. Callavei*, *Chonograptus tenellus*, and *Ch. flexilis*.

The greater part of the Isle of Man is occupied by a similar series of slates and grits, now known as the *Manx slates*. These have been divided by Mr. Lamplugh into three portions which seem to be consecutive, though no recognisable fossils have been found in any of them, and the crush-phenomena produced by lateral compression are even more strongly developed in that island than in Cumberland.¹⁹

The subdivisions traced by Mr. Lamplugh strike from N.E. to S.W., and the *Lonan flags* on the eastern side are believed to be the lowest; these seem originally to have been flagstones, mudstones, and shales, but are now hard, cleaved, crumpled, and frilled rocks. North-west of them is a band of quartz-veined, thin-bedded grits (the *Agneash grits*), and west of them are the *Barrule slates*, a mass of dark-blue slaty rocks, which closely resemble the Skiddaw slates. Of the Lonan flags Mr. Lamplugh observes that lithologically they have a close resemblance to the Bray Head Series described below.

4. Ireland

So far as present knowledge extends Cambrian rocks only occur in the south-east of Ireland in the counties of Dublin, Wicklow, and Wexford. The facies is one of grits, flagstones, and shales like that of Wales, but the base is not exposed and none of the Welsh fossils have yet been discovered in the Irish area. The rocks are indeed so cleaved and altered by metamorphic agencies that until recently it has been an open question whether they were of Eparchæan or Cambrian age.

The determination of their age rests mainly on the discovery of their characteristic fossil *Oldhamia* (see Fig. 12) in rocks of Cambrian age elsewhere. It is certainly curious that *Oldhamia* should not have been found in the Cambrian of Wales, but in the

Ardennes of North-west France both the Irish species of *Oldhamia* occur in the slates of Fumay which underlie beds of Tremadoc age. *Oldhamia radiata* has also been found in Belgium, and another species (*O. occidentis*) has been obtained from the Upper Cambrian of North America.

In further confirmation of this determination of age it has been ascertained that the supposed unconformity between the Arenig Beds and the underlying rocks in Ireland is of an illusory character. The beds formerly regarded as conglomerates in Wexford have proved to be crush-breccias, and elsewhere the junction beds of the two series are so plicated into one another that it is impossible to find a dividing line, and so far as Messrs. Egan and M'Henry could ascertain in their revision of 1898,²⁰ there is no evidence of any stratigraphical break between them.

One of the best sections of these Cambrian rocks is that exhibited in the cliffs of Bray Head near Dublin, whence they are sometimes called the *Bray Head Series*. At the northern end of this cliff section are red, purple, and green slates and grits, succeeded on the south by alternating grits and shales. The beds are bent into numerous sharp folds, so that the real thickness is much less than appears at first sight. Jukes and Du Noyer estimated the exposed succession at between 3000 and 4000 feet, but neither the base nor summit is actually visible. These rocks are also well exposed on the coast of Howth, east of Dublin, where they include some remarkable breccias.

No fossils have been found in these beds except the two or three species of *Oldhamia*, the trumpet-shaped worm-tubes known as *Histioderma*, and some spherical bodies with radiating spines which may be *Radiolaria*. The nature of the markings called *Oldhamia* has not been definitely ascertained; Professor Sollas has pointed out that those of *O. radiata* are grooves and may have been made by the anterior end of a worm, but those of *O. antiqua* are ridges on the upper sur-

Fig. 28.—GENERALISED SECTION ACROSS THE NORTH-EAST OF SCOTLAND (after Messrs. Peach and Horne).

a, f. Moine schists.
 b. Torridon sandstone.
 c. Cambrian quartzites.
 d. Serpulite grit.
 e. Durness limestone.
 h. Hebridean gneiss.

faces of bedding planes, and no explanation of them has yet been suggested.

5. Scotland

In the north-west of Scotland Cambrian rocks flank the eastern side of the tract occupied by the Hebridean and Torridonian, all the way from Durness and Eriboll on the north coast down to the island of Skye. Before the discovery of *Olenellus* in these rocks they were supposed to be of Ordovician age.

In the north of Sutherland there are two tracts of Cambrian, the relative positions of which are shown in Fig. 23. The beds of the Durness area are arranged in the form of a basin truncated on the eastern side by a fault which brings them against the Archæan gneiss; on the west they are seen to rest unconformably on this gneiss and on the red Torridon sandstone. The Durness basin is separated from that of Loch Eriboll by a prominent ridge of Archæan gneiss, which, however, bears an outlier of the Cambrian basement beds. The Eriboll area exhibits the same series as that of Durness, but they are crushed and faulted in a remarkable manner, and are cut off on the east by a *thrust-plane*, which carries some of the Archæan gneiss over the Cambrian Series, so that here the ordinary test of age by superposition becomes useless.

The total thickness of the beds composing the Cambrian System of Scotland is estimated as at least 2000 feet, but the upper limit is not reached, being everywhere concealed beneath the masses of crushed and sheared rock which have been carried westward onto and over the Cambrian strata. The exposed portion is divisible into two series, an arenaceous below and a calcareous series above. These can also be subdivided as follows:—²¹

Calcareous Series or Durness limestone, 1400 feet	{	3. Grey limestones, some dark and some light grey, with many layers of chert; many fossils throughout.	
		2. Dolomitic limestones, grey, white, mottled, and pink, with layers of chert nodules. The Sangomore and Sailmhor Groups. Few fossils.	
		1. Light-coloured dolomites and limestones, with bands of chert.	
Arenaceous Series, 720 feet	{	5. Dolomites and limestones with <i>Salterella</i> .	} 200 feet.
		4. Dolomitic grits with <i>Salterella</i> (Serpulite grit)	
		3. Calcareous mudstones (Fucoid Beds)	
		2. Fine-grained quartzites perforated by worm burrows (pipe rock). 300 feet.	
		1. Coarse flaggy grits and quartzites, with a basement bed of brecciated conglomerate. 200 feet.	

The most abundant fossils in the Durness limestone are Cephalopoda—*Orthoceras*, *Piloceras*, and *Lituites*. Next in number

are Gastropoda, but bivalves (Lamellibranchia and Brachiopoda) are not rare. *Archæocyathus* (see p. 72) is of frequent occurrence, as are also sponges of the genus *Calathium* or *Archæoscyphia*.

In 1891 fragments of *Olenellus* (*O. Lapworthi*) and specimens of *Hyolithes* were found in the Serpulite grits and Furoid Beds of Ross, proving them to be of Lower Cambrian age. Hence it is probable that the lower part of the Calcareous Series is of Middle Cambrian age (Paradoxidian), but the higher and more fossiliferous part is of Upper Cambrian age, corresponding to the Upper Lingula flags and Tremadoc slates of Wales.

The Cambrian succession in Skye has been worked out by Mr. C. T. Clough, who found that the same subdivision could be made as in Durness. Moreover, the *Olenellus* fauna was again discovered in the Furoid Beds at Tokavaig and Ord. No fossils, however, could be found in the lower part of the Durness limestone, the thickness of which to the top of the Sailmhor Group Mr. Clough estimates at 830 feet. But higher beds are found in Strath, and in 1898 these yielded many fossils, including *Calathium* and *Archæoscyphia*; a trilobite of the genus *Solenopleura*; *Orthosina festinata* and *O. striatula*; a bivalve, *Euchasma Blumenbachiae*; species of *Pleurotomaria*, *Murchisonia*, *Maclurea*, and *Holopea*, with *Piloceras*, *Orthoceras*, and *Trecholites*.

The fauna of the Durness limestone, as regards both genera and species, has much more affinity with that of the Cambrian of North America than with that of Wales or England. It may in fact be inferred that the Scotch Cambrian belongs to a North Atlantic or North American area of life and deposition, in which the physical conditions differed considerably from those of the South British and Central European area.

The only other part of Scotland where rocks occur which seem to be of Cambrian age is along the south-eastern border of the Central Highlands in Perth, Forfar, and Kincardine. They occur in narrow faulted strips along a line from Blairgowrie in Perth to Stonehaven on the coast, and consist of grey shales and grits, jasper and jaspery phyllite, with lenticular sills and possibly interbedded flows of basic igneous rock (dolerite). They were described by Mr. G. Barrow as the "Green Rock and Jasper Series,"²³ and from the resemblance between them and rocks of Arenig age in the Southern Uplands he regarded them as probably Ordovician; but a more recent discovery of fossils in the same series as exposed on the coast near Stonehaven makes it probable that they are of Cambrian age.

This discovery was made by Mr. R. Campbell²³ in a set of black shales with layers of jasper and chert intercalated with bands or sills

CORRELATION TABLE OF BRITISH CAMBRIAN ROCKS

Upper.	South Wales.	North Wales.	Malvern Hills and Shropshire.	Warwickshire.	Cumberland.	Scotland.	
	Upper and Lower Tremadoc, 1000 feet.	Upper and Lower Tremadoc, ? 1200 feet.	Shinerton and Malvern grey shales, 1500 feet.	Merevale shales, 200 feet.	Lower Skiddaw slates.	Upper Durness limestones, 600 feet.	
	Lingula Flags— Upper, Middle, Lower, 2000 feet.	Lingula Flags— Dolgelly, Ffestiniog, Maentwrog, 6000 feet.	Black shales of Malvern, 800 feet. Wanting.	Oldbury shales, 1000 feet. ?		Middle and Lower Durness limestones, 800 feet.	
	Menevian, 750 feet.	Menevian, 250 feet.	Wanting.	Purley shales, 600 feet.			
Middle.	Solva Series, 1800 feet.	Upper Harlech Beds, 2600 feet.	Upper Comley grits and shales.	?			
	Caerfai Series, with Olenellus, 1600 feet.	Rhinog Grits, Cefn Slates, Dolwen Grits, 3000 feet.	Hollybush and Comley sandstones. Quartzites, 800 feet.	Hartshill quartzites, 600 feet.		Serpulite Grit and Quartzite Series, 700 feet.	
Lower.							

of green igneous rock. Dr. Peach reports that the fossils include species of *Lingulella*, *Obolella*, *Acrotreta*, *Linnarssonina*, and *Siphonotreta*, and a few specimens of a Phyllocarid Crustacean allied to *Lingulocaris*. These genera, he remarks, are found in both Upper Cambrian and Lower Ordovician, but the absence of graptolites is indicative of the former rather than the latter.

D. THE CAMBRIAN OF NORTHERN EUROPE

1. France (North-West)

Cambrian strata are found in many parts of Brittany and Normandy troughed in between the tracts of Archaean rocks, the main flexures of the district striking roughly from west to east. The system is most fully developed in the southern and eastern parts of the region, some portions of it being apparently absent in the west and north.

In the north-west (around Brest and Tréguier) the Cambrian Series consists of two groups differing much in lithological characters. These are (1) a basal purple conglomerate passing up into sandstones, 300 to 500 feet, (2) purple and green slates, about 400 feet.²⁴ No fossils have been found in these rocks, and they are succeeded by coarse grey felspathic sandstones (*Grès felspathique*), which are either of Tremadoc or Arenig age.

In the south and south-east of Brittany the Cambrian is represented by much thicker masses of deposit. Thus to the south and west of Rennes the purple conglomerate and sandstone is 1700 feet thick, and the overlying slates are estimated to be 7000 feet. Farther east in Mayenne there is a more varied series comprising a basal conglomerate, purple slates with beds of grit and limestone, coarse sandstones, and andesitic lavas, with finally green slates containing *Lingulella Criei*. In the lower beds only a few specimens of *Lingulella* and *Dinobolus* have yet been found, but Mr. Ählert believes them to represent the whole of the Lower and Middle Cambrian Series (Olenellian and Paradoxidian).²⁵

The correlation of the southern and northern series is not easy because of the rarity of fossils. Professor de Lapparent gave no definite correlation, but seemed to assume that the basal conglomerates are everywhere of the same age. If this is so then there is probably a gap in the northern series between the slates and the *Grès felspathique*. On the other hand, the northern area may have been land in Lower Cambrian time, and the conglomerates may be shore deposits which would be of later and later date as we passed from south to north and

north-west, till only the Upper Cambrian is represented. On this view the correlation would be as follows, and the great difference in thickness more easily accounted for:—

	Southern area.	Northern area.	
8000 feet.	Green and purple slates.	Green and purple slates	} 880 feet.
	Felspathic sandstones and lavas.	Purple sandstones, etc.	
	Purple slates.		
	Purple sandstones.		
	Basal conglomerate.		

In Normandy a somewhat different facies of the Cambrian is found, inasmuch as it includes an important limestone formation which is largely quarried for marble. Near Caen, May, and Clécy the succession is:—

	Feet.
Green slates and limestone, without fossils	130
Massive limestones (red and grey marbles)	250
Red slates and red marble	20
Purple sandstone and conglomerate	200
	<hr/> 600

All these beds thicken southward till, near Montbard and Fourneaux, they have a combined thickness of nearly 2000 feet, while the overlying felspathic sandstones thin out entirely, and finally, south of St. Lo, the whole series disappears beneath an overstep of the *Grès armoricain* (Arenig) on to the Archæan rocks, and the Cambrian only comes in again to the south of Ernée and Mayenne.

2. Iberian Peninsula

Cambrian rocks occur in several parts of Spain and Portugal, in Asturias and Galicia, in Leon, in Seville near Ciudad-Real, and near Busaco in Portugal; the *Paradoxides* fauna having been found in several of these districts. The area which has been most completely explored and described is that of Asturias and Galicia in the north-west, and in 1882 Dr. Barrois referred the following groups to the Cambrian:—²⁵

La Vega Beds	{ Greenish sandy shales with beds of green sandstone—100 to 300 feet.
	{ Limestones and shales—60 to 200 feet.
Rivadeo Beds	{ Green quartzites and slates.
	{ Green slates and bluish phyllites.

The upper group yielded species of *Paradoxides*, *Conocoryphe*, *Arionellus*, and *Trochocystites bohemicus*, so that it is clearly of Middle Cambrian age. It is overlain by conglomerates and sandstones with *Bilobites* which are comparable with the *Grès fels-*

pathique of Brittany, and there is consequently an absence of the Upper Cambrian (*Olenus* fauna). Below the La Vega Beds and apparently in conformable succession are the unfossiliferous Rivadeo slates, which may in part represent the Lower Cambrian, but Dr. Barrois compared them with the Phyllades de St. Lo which were at that time classed as Cambrian. Further investigation is therefore required in this area where no base has yet been recognised.

3. *Belgium and the Ardennes*

In the Ardennes district there are four separate areas where Cambrian rocks come to the surface, but only those of Rocroi and of Stavelot are of any considerable size.²⁷ The one lies mostly in France, forming a hilly plateau traversed by the deep ravine of the Meuse between Deville and Fumay; the other is on the borders of Belgium and Germany around Spa and Stavelot. The rocks have the same facies in both areas; they are much flexured and faulted, but a definite succession has been made and the Belgian geologists group them in three stages as below:—

3. *Salmian*, consisting of slates and quartzo-phyllites in which *Dictyograptus* has been found.
2. *Revinian*, black slates and dark-grey quartzites.
1. *Devillian*, greenish and grey quartzites with bands of purple and green slate containing *Oldhamia*.

The base is not exposed, and no fossils except *Oldhamia radiata* and *O. antiqua* have been found in the Devillian, which may be of Middle or Upper Cambrian age; while the Salmian may certainly be correlated with the British Tremadoc Beds.

In Belgium there is another area where a succession of Cambrian rocks are found, *i.e.* in the valley of the Thyle south of Brussels. Here the lowest beds resemble the Devillian and also contain *Oldhamia*; above them, near Mousty, M. Malaise has described a set of black slaty shales with black limestones and bands of chert, and in the limestones he has found small Ostracoda which he refers to *Leperditia punctatissima* and *Primitia solvensis* (*Lingula* flag species); these black beds are succeeded by quartzo-phyllades which he also refers to the *Lingula* flags, and he correlates the Cambrian of the Ardennes and of Brabant as follows:—²⁸

Ardennes.		Brabant.	
Salmian	{ Upper.	.	Not recognised.
	{ Lower.	.	Assize de Villers.
Revinian	.	.	Assize de Mousty.
Devillian	{ Upper	.	Assize de Tubize.
	{ Lower	.	Assize de Blaumont.

In connection with the Cambrian Series of Belgium the recent recognition of similar rocks beneath the eastern counties of England is of much interest, for at Stutton near Ipswich the boring made in 1894-5 entered hard quartzitic rocks at a depth of 994 feet, and traversed them to a total depth of 1525 feet. These rocks are really dark-grey quartzo-phyllades, which M. Murlon has recognised as resembling those of Villers, near Ath. At Harwich and Weeley in Essex the rocks found below the Gault are dark-grey and purple slates, in which an *Orthoceras* was found. These must be either of Tremadoc age or a part of the overlying Ordovician Series as developed in Belgium.

4. Scandinavia

It is interesting to note that in Norway, Sweden, and Northern Russia the Cambrian strata occur in broad, flat-lying sheets as originally deposited, and are so little altered that they have more the aspect of our Mesozoic clays, shales, and sandstones than of Palæozoic rocks. Moreover, those of Scandinavia present a complete succession of highly fossiliferous beds, and yet their thickness is only a few hundred feet.

The Cambrian Series of this region consists everywhere of a lower arenaceous division and an upper argillaceous division, the lower being from 350 to 550 feet thick and the upper from 200 to 400 feet. The system is most fully developed in Sweden, and especially in the districts of Scania and Westrogothia, where there is the following succession in descending order (slightly altered from Linnarsson and Tullberg).²⁹

IV. *Passage Beds* (thickness about 50 feet=Tremadoc).

3. *Ceratopyge* limestone, with *C. forficula*.
2. Shumardia shales.

1. *Dictyograptus* shales, with *Dictyograptus* and *Obolella Salteri*.

III. *Olenus* shales in five zones, with three bands of limestone, thickness from 70 to 200 feet (=Lingula flags).

5. Zone of *Parabolina heres*.
4. Zone of *Peltura scarabæoides* and *Sphærophthalmus alatus*.
3. Zone of *Eurycare* and *Leptoplastus*.
2. Zone of *Parabolina spinulosa*.
1. Zone of *Olenus truncatus*, *O. gibbosus*, and *Ag. pisiformis*.

II. *Paradoxides* shales, divisible into four principal zones, and from 80 to 160 feet thick (=Menevian and Solva Beds).

4. The Andrarum limestone with 5 feet of shale above; *Agnostus levigatus*, *Paradoxides Forchhammeri*, and *Orthis Hicksi*.
3. Zone of *Par. Davidis* and *Conocoryphe aqualis*.
2. Zone of *Par. Tessini* with the *exsulans* limestone at base containing *Conocoryphe exsulans* and *Par. palpebrosus*.
1. Zone of *Agnostus atavus*, *Paradoxides olandicus*, and the black Alum shale at the base.

1. *Olenellus Beds*, chiefly sandstones homotaxial with the Hartshill quartzite and Caerfai Beds, 350 to 550 feet.
 4. Phosphatic limestone (few fossils).
 3. Sandy shales with *Olenellus Kjerulfi* and *Arionellus primævus* (5 to 10 feet).
 2. Fucoid sandstone with *Obolella favosa*, 200 to 350 feet.
 1. Eophyton sandstone with *Mickwitzia monilifera* and the markings called *Eophyton* and *Cruziana*, 150 to 200 feet.

The basal sandstones rest unconformably upon the Archæan gneisses.

5. Russia

In the Baltic provinces of Russia there is a still more remarkable development of the Cambrian System. The arenaceous division is partly replaced by blue clay, and the black trilobite shales are absent. The succession is as follows:—

		Feet.
Upper. Lower.	6. Glauconitic sand with <i>Obolus</i> and <i>Siphonotreta</i>	10
	5. Shales with <i>Dictyograptus</i> and <i>Bryograptus</i>	20
	4. The Ungulite sandstone full of <i>Obolus Apollinis</i> and other minute Brachiopods	4
	3. Alternating clays and sandstones with <i>Olenellus Michwitzii</i> , <i>Mickwitzia monilifera</i> , and a <i>Scenella</i>	50
	2. The blue clay, without fossils	300
	1. Ferruginous sandstones, resting on granitoid rock	300
		684

Professor F. Schmidt³⁰ has pointed out that the base of the Ungulite sandstone is sharply divided from the beds below, and sometimes contains pebbles derived from them. Hence there appears to be a gap at this point, which will account for the complete absence of any representatives of the Paradoxides and Olenus shales, unless the thin band of Ungulite sandstone is a partial equivalent of the latter. The underlying clays and sandstones are evidently the equivalents of the Fucoid and Eophyton sandstones, while the two highest members are comparable with the beds which occupy the same position in Sweden.

6. Germany and Bohemia

It is very probable that Cambrian rocks underlie the greater part of Germany, but they are only exposed in a few places. One of these is the Hohe Venn, south of Aix-la-Chapelle, where there are slates, quartzites, and phyllites, resembling those of the Ardennes and containing both *Oldhamia* and *Dictyograptus*. Another and larger area is found in the Fichtel Mountains and the

Thuringia Wald, north-east of Bavaria, but it is only at Leimitz, near Hof, that well-preserved fossils have been obtained; the fauna, consisting chiefly of Trilobites, Brachiopoda, and a few Cystidea, appears to belong to the highest Cambrian (Upper Tremadoc and Ceratopyge limestone).

In Bohemia the existence of Cambrian rocks was first made known by Barrande in 1852, when he recognised his Stage C as containing a "primordial fauna." Subsequent writers have modified Barrande's classification, and have found a still older fauna in his Stage B. To agree with the British Cambrian System it must also include part of D, and will then consist of the following groups:—

Stage D 1. Pisolitic ironstones, sandstones, and sandy conglomerates with diabasic lavas and tuffs.

Stage C. Greenish slates with a *Paradoxides* fauna (*P. bohemicus* and *P. spinulosus*), *Conocoryphe*, *Arionellus*, *Ellipsocephalus*, etc.

Stage B. Sandstones and flags with an *Olenellus* fauna passing down into coarse conglomerate which rests unconformably on Stage A (Przibram schists).

A more detailed study of this Cambrian Series has been made by Pompeckj,³¹ who describes the lowest part (Stage B) as consisting of a conglomerate passing up into grits, sandstones, and flags which contain species of the Trilobites *Sao*, *Solenopleura*, *Ellipsocephalus*, and *Ptychoparia*, with *Stenotheca* and *Orthis*; this is an *Olenellus* fauna, though that genus has not yet been found. Dr. Marr³² remarks that these rocks strongly resemble our Harlech Series and are of great thickness. The *Paradoxides* Beds are slaty shales with a thickness of about 1000 feet. Above them is a conglomerate supporting greenish grits which contain *Lingula Feistmanteli* and probably represent part of our *Lingula* flags. Above these are pisolitic ironstones of black, green, and red colours which contain a few fossils—*Erinnys Grimmi*, *Amphion Lindnaueri*, and *Orthis desiderata*; this small assemblage having the aspect of a passage fauna and being therefore probably of Tremadoc age.

From this account it will be seen that the Bohemian sequence is not quite complete; in fact, there seems to be a break and unconformity between Stages C and D. The beds of Stages B and C are only found over a small portion of the area near the town of Beroun, and are overlapped by the conglomerates of D 1 which then rest directly on the Archæan rocks. Moreover, no species of *Olenus* has yet been found in Bohemia, from which it may be inferred that there is little if anything to represent the lower and middle parts of our *Lingula* flags, the *Lingula* grits of Stage D corresponding probably with the Dolgelly Beds of Wales. The

total thickness of the Cambrian in Bohemia may be about 3000 feet.

The only other exposure of Cambrian rocks in Central Europe is in Russian Poland, round Sandomir on the Vistula, where some shales, associated with quartzites and conglomerates, have yielded species of *Paradoxides* (? *P. bohemicus*), *Agnostus* (*fullax* and *gibbus*), and *Liostracus Linnarsoni*; evidently a Middle Cambrian fauna.

E. EUROPEAN GEOGRAPHY AND CONDITIONS OF DEPOSITION

Any attempt to restore the geographical conditions of the early Palæozoic periods must be a task of great difficulty. There are large areas where the rocks of these early systems are deeply buried below those of newer times, and the exposures which we can study are only so many isolated portions of some ancient sea-floor; while the traces of contemporaneous lands are only to be found where some series of strata are absent or where coarse detrital deposits are unusually thick. Nevertheless, wherever Palæozoic rocks can be followed over a considerable area some indications of the direction from which the sediment was transported can usually be found, and of the conditions under which it was deposited.

It will therefore be useful to indicate such evidence as we possess for answering the question—under what geographical and physical conditions were the Cambrian strata of Northern and Western Europe accumulated?

In the first place, some general considerations are suggested by a comparison of the deposits in Wales, England, Sweden, and Russia. The enormous thickness of the Welsh Cambrians, which have a maximum thickness of about 11,000 feet, as compared with a possible 3000 feet in Warwickshire, less than 1000 feet in Sweden, and only 680 feet in Russia, is a point of great significance; but the inference to be drawn from these figures depends on other stratigraphical facts. If the lower beds were not represented in the Swedish and Russian succession, it might be inferred that the north of Europe was a land-area during the earlier part of the period, and was gradually submerged by the waters of a sea which spread over it from the south-west, and this view was actually suggested in 1876 before the *Olenellus* fauna was recognised in Europe. The facts as we now know them, however, will not allow of such an inference; the Swedish succession is as complete as that of Warwickshire or South Wales, and the difference in thickness is caused mainly by the great increase in the amount of sandy material in the Cambrian sediments as we pass from east to west, or rather from north-east to south-west.

In the western areas arenaceous material prevails not only in the Lower Cambrian, but also in the Middle and Upper divisions, for in North Wales a large part of the Lingula Flag Series consists of flagstones which become coarse quartzose grits as they are followed through Carnarvonshire. On the other hand, in Scotland, Sweden, and Russia sandstone is practically confined to the lowest stage, all the higher portions of the system consisting of limestone and shale.

As the Swedish geologist Linnarsson wrote in 1876, "The facts rather tend to show that most of the Swedish Cambrian rocks were deposited in a deeper sea and farther from land than the British." He points out that the small thickness of the *Olenus* Beds over such a large area in Sweden can only be explained on this view, for they are so thin compared with the Lingula flags of Wales that the rate at which sediment was accumulated in Wales must have been fifty or sixty times as rapid as it was in Sweden. This must have been due to the much greater proximity of land, while all the facts connected with the Upper Cambrians of Sweden lead us to infer that they were deposited in a deep sea and far from land.

We may therefore conclude that the greater part of the materials forming the Cambrian deposits in France, Wales, and England were derived from lands which lay to the west of France and to the north-west of Wales. That which lay west of France and south-west of Wales was probably part of a large land-area or continent, occupying part of what is now the Atlantic Ocean, and terminating eastward in a promontory which included the northern part of Brittany during early Cambrian time, but was submerged in the later part of the period.

The land to the north-west of Wales may have been an island or another promontory of the Atlantic continent. It included Anglesey and probably stretched across the Irish Sea into Ireland, but until more is known about the structure of the north of Ireland it is impossible to say how far it reached in that direction.

Open sea seems to have extended across the North Atlantic region from America to the north of Scotland with circumpolar or Arctic land again to the north of it, for it is only in this way that the American character of the Scottish Cambrian fauna can be satisfactorily accounted for (see *The Building of the British Isles*, 3rd edition, p. 63). This northern sea may not have been very deep, but its waters must have become deep enough and clear enough in Middle Cambrian time for the formation of limestone, and in the Scottish limestones there is evidence that the accumulation of shell-debris and calcareous matter went on very slowly; for

the condition of the larger fossils in these beds is such that they must have lain for a long time on the sea-floor and have suffered greatly from decay and partial solution before they were protected by a covering of other calcareous materials.

Mr. Peach³³ has observed that the shells are generally imperfect and seldom show the external markings; the Lamellibranchs, though often found with attached valves and in their natural position, are yet often so imperfect that they have clearly suffered much from solution before complete embedment. Again the outer walls and the septa of the chambered Cephalopods have in most cases been largely or wholly destroyed, so as to leave only the thick column of the central siphuncular portion of the shell.

Moreover, these limestones contain many nodules of chert arranged in layers like the flints and cherts in Cretaceous deposits, and sometimes in continuous layers or sheets. These cherts contain sponge-spicules, and though no Radiolaria can now be recognised in them it is very probable that the silica was derived partly from Radiolaria and partly from siliceous sponges.

The occurrence of glauconite grains in certain beds, not only in Scotland but in the Upper Cambrian of Sweden and Russia, is also indicative of clear water, slow deposition, and some distance from land; for it is probable that the conditions favourable for the production of glauconite on sea-floors have not materially changed from Cambrian time to the present day. Those conditions are found where the water is clear and the bottom currents are fairly strong but carry little sediment, and where the depth of water is from 200 to 500 fathoms; the actual depth, however, seems to be less important than the other conditions.

Passing now to the more southern parts of the European region we find proofs of the existence of a Cambrian Sea in Portugal, Spain, Provence, and Sardinia; so that it seems probable that the whole of Western and Southern Europe was covered by this sea, though there may have been islands within its limits. It is only in Bohemia that we seem to approach one of the borders of this sea, for there the older Cambrian deposits are limited to one part of the area, the Upper Cambrian overlapping on to Archæan rocks. Even this land may have been an island, but if it was part of a large tract that must have lain to the east or south of Bohemia.

Another point to be noted with regard to the physical conditions of Cambrian time is that very little volcanic activity showed itself in the European region till toward the close of the period. After the violent and long-continued outbursts of volcanic energy which prevailed in pre-Cambrian times, there seems to have been a period of quiescence and subsidence before the subterranean forces acquired

power enough to burst forth again into surface eruptions. During the later part of the period volcanic activity became rife in several parts of the region, notably in Wales, Brittany, and Bohemia.

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- ²⁹ See Mobery in *Geol. Foren. Stockholm. Forandl.* for 1910.
- ³⁰ Schmidt, *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 514.
- ³¹ Pompeckj, *Jahrb. K. K. Geol. Reichsaust.* xlv. p. 495.
- ³² Marr, *Palæozoic Rocks*, Sedgwick Prize Essay for.
- ³³ Peach in "Geol. Structure of the N.W. Highlands."

CHAPTER VI

THE ORDOVICIAN SYSTEM

A. NOMENCLATURE AND DIVISIONS

THE grounds on which this system has been established have already been explained (see p. 70). It is the *Upper Cambrian* of Sedgwick and the *Lower Silurian* of Murchison and the Geological Survey. The system has usually been divided into three series with the following names :—

3. Upper Ordovician or Bala Series.
2. Middle Ordovician or Llandilo Series.
1. Lower Ordovician or Arenig Series.

The names are taken from places in Wales where the several series are well developed, *i.e.* the Arenig Mountains in Merioneth, the town of Llandilo in Carmarthenshire, and the town of Bala in Merioneth. This succession was first established in North Wales by Sedgwick. Part of it was studied at the same time in Shropshire and Carmarthen by Murchison, who described the local equivalents of the Bala Series under the name of Caradoc Sandstone, and after their identity had been demonstrated the beds were for a time called the Bala and Caradoc Series.

These divisions, however, were not separately mapped either by Murchison or by the Geological Survey, so that they were never clearly marked off from one another, nor was any definite horizon recognised as the base of the Llandilo Series or as that of the Bala Series. The first to establish divisions on a strictly palaeontological basis was Dr. H. Hicks¹ who in 1875 recognised both the Arenig and Llandilo Beds in Pembrokeshire, and subsequently found that they were separated by a set of black shales which contained a new and distinct fauna.² These he called the Llanvirn Beds, but for a long time this group was regarded as a superfluous division, only embodying what should or could be classified as the Upper Arenig and the Lower Llandilo stages.

Gradually, however, it has been found that the fauna of the Llanvirn Beds has more than a local value and is really distinct from those above and below. A portion of the Llanvirnian outcrop was mapped by Messrs. Marr and Roberts in 1885,³ and other portions subsequently by the Geological Survey, with the result that in a recent memoir Dr. Strahan announces that the only possible course is to restrict both the Arenig and Llandilo Series, and to establish an intermediate Llanvirn Series.⁴

Dr. Marr has also advocated the separation of the Upper Bala from the rest of that series because it contains many species which do not occur or are rare in the lower beds, but the true value of this *Ashgillian* fauna has yet to be proved, and in this volume I shall not recognise more than four main divisions in the Ordovician System, namely:—

4. Bala Series (Ashgillian and Caradocian).
3. Llandilo Series or Llandeilian.
2. Llanvirn Series or Llanvirnian.
1. Arenig Series or Arenician.

B. LIFE OF THE PERIOD

Taken as a whole, the special features of the Ordovician fauna are (1) the abundance of branched and biserial graptolites belonging to the families *Dichograptidæ*, *Dicranograptidæ*, *Glossograptidæ*, *Leptograptidæ*, and *Diplograptidæ*. Of these the first includes the following genera—*Dichograptus*, *Tetragraptus*, *Loganograptus*, *Didymograptus*, and *Phyllograptus*; in the *Dicranograptidæ* are *Dicellograptus* and *Dicranograptus*. The *Glossograptidæ* include *Glossograptus* and *Lasiograptus*. The *Leptograptidæ* include *Leptograptus* and *Nemagraptus* (= *Cenograptus*), while *Diplograptus*, *Cryptograptus*, and *Climacograptus* belong to the *Diplograptidæ*.

(2) The appearance of many new trilobite genera—**Æglina*, *Acidaspis*, *Ampyx*, **Amphion*, *Asaphus*, *Calymene*, *Encrinurus*, *Harpes*, *Homalonotus*, *Ilænus*, *Lichas*, *Phacops*, **Placoparia*, *Proëtus*, *Remopleurides*, *Sphærexochus*, *Staurocephalus*, **Stygina*, and **Trinucleus*, those with an asterisk not surviving this period.

(3) The abundance of Cystideans, eight genera, and twenty-three species, occurring in the Bala Group.

(4) The abundance of Orthidæ, and the appearance of the following genera of Brachiopoda—*Atrypa*, *Leptæna*, **Orthisina*, *Rhynchonella*, *Siphonotreta*, *Strophomena*, *Trematis*, and *Triplexia*.

The occurrence of graptolites throughout the Ordovician System in almost all areas where shales were deposited has afforded a means of subdivision into stages or zones and of correlating the

successive members of one local series with those of another and with those of other countries. The following is a table of the zones recognised in the British Islands:—

	Zone of <i>Dicellograptus anceps</i> .	
Bala Series	"	" <i>complanatus</i> .
	"	<i>Pleurograptus linearis</i> .
	"	<i>Dicranograptus Clingani</i> .
	"	<i>Climacograptus Wilsoni</i> .
Llandilian	"	<i>Didymograptus superstes</i> .
	"	<i>Dicellograptus divaricatus</i> .
Llanvirnian	"	<i>Didymograptus Murchisoni</i> .
	"	" <i>bifidus</i> .
Arenician	"	" <i>hirundo</i> .
	"	" <i>extensus</i> .

Fig. 24.—GROUP OF ARENIG AND SKIDDAW GRAPTOLITES.

1. <i>Didymograptus hirundo</i> .	3. <i>Cryptograptus antennarius</i> .
2. <i>Didymograptus gibberulus</i> .	4. <i>Phyllograptus typus</i> .
5. <i>Tetragraptus quadribrachiatulus</i> .	

The following are the principal species which characterise the several divisions of the Ordovician System:—

Fossils of the Arenig Series

Hydrozoa. *Tetragraptus quadribrachiatulus*, *T. serra*, *Didymograptus extensus*, *D. hirundo*, *D. gibberulus*, *Phyllograptus typus*, *Dendrograptus arbuscula*, *Diplograptus dentatus*, *Azygograptus suecicus*.

- Crustacea.* Ogygia Selwyni, O. marginata, Ægina binodosa, Æ. caliginosa, Calymene parvifrons, Caryocaris Wrighti.
Brachiopoda. Lingula petalon, Monobolina plumbea, Orthis alata.
Lamellibranchia. Redonia anglica, Palæarca amygdalus.
Gastropoda. Hyolithes (Theca) vaginula.
Cephalopoda. Orthoceras sericeum.

Fossils of the Llanvirn Series

- Hydrozoa.* Didymograptus bifidus, Did. Murchisoni, Did. nanus, Did. acutidens, Diplograptus (Amplexograptus) confertus, Diplograptus calcaratus, Glossograptus ciliatus.
Trilobita. Ampyx nudus, Ilænus Hughesi, Placoparia cambrensis, Phacops llanvirnensis, Barrandea Homfrayi.
Brachiopoda. Lingula attenuata.

Fig. 25.—GROUP OF ARENIG FOSSILS.

- a. Ogygia Selwyni.
 b. Ægina binodosa.
 c. Palæarca amygdalus.
 d. Euomphalus corndensis.

- Gastropoda.* Euomphalus corndensis, Pleurotomaria llanvirnensis, Conularia llanvirnensis, Bellerophon perturbatus.
Cephalopoda. Conoceras llanvirnense, Orthoceras caeresiense.

Fossils of the Llandilo Series

- Radiolaria.* Species of Styptosphæra, Spongoplegma, Diploplegma, Stauroplegma, Haliomma, Dorysphæra, Doryplegma, Triposphæra.
Foraminifera. Saccammina Carteri.
Hydrozoa. Didymograptus superstes, Diplograptus foliaceus, Dicollograptus divaricatus, and D. sextans, Nemagraptus (Cenograptus) gracilis, Dieranograptus ramosus.
Crustacea. Asaphus tyrannus, Ogygia Buchi, Ampyx nudus, Trinucleus fimbriatus, Agnostus M'Coyi, Acidaspis Jamesi.
Brachiopoda. Lingula brevis, Orthis alata, O. confinis, Siphonotreta micula (ranges into Bala).
Gastropoda. Maclurea Logani, M. magna, Ophileta compacta, Bellerophon perturbatus (passes to Bala).
Cephalopoda. Orthoceras Avelinei.

Fig. 26.—GROUP OF ARENIG AND LLANDILO FOSSILS.

- a. *Didynograptus Murchisoni*.
 b. *Acidaspis Jamesi* (Irish).
 c. *Orthis alata* (Arenig).'

- d. *Trinuclaus fimbriatus*.
 e. *Asaphus tyrannus*.
 f. *Ogygia Buchi*.

Fig. 27.—GROUP OF LLANDILO AND HALA GRAPTOLITES.

1. *Climacograptus bicornis*.
 2. *Dicellograptus sextans*.
 3. *Dicellograptus ziczac*.

4. *Glossograptus Huxleyi*.
 5. *Dicranograptus ramosus*.
 6. *Diplograptus foliaceus*.

Fig. 28.—GROUP OF BALA FOSSILS.

<i>a.</i> <i>Orthis flabellulum.</i>	<i>d.</i> <i>Modiolopsis expansa.</i>
<i>b.</i> <i>Orthis elegantula.</i>	<i>e.</i> <i>Holopea concinna.</i>
<i>c.</i> <i>Ctenodonta semitruncata.</i>	<i>f.</i> <i>Lituities hibernicus.</i>

Fig. 29.—GROUP OF BALA FOSSILS.

<i>a.</i> <i>Echinospiera aurantium.</i>	<i>d.</i> <i>Lichas hibernicus.</i>
<i>b.</i> <i>Sphaeronites munitus.</i>	<i>e.</i> <i>Phacops apiculatus.</i>
<i>c.</i> <i>Ilanus Davisii.</i>	<i>f.</i> <i>Agnostus trinodus.</i>

Fossils of the Bala Series

- Actinozoa.* Favosites crassa, Monticulipora fibrosa, Nebulipora lens, Lyopora favosa, Halysites catenularius.
- Hydrozoa.* Climacograptus Wilsoni, Diceranograptus Clingani, Pleurograptus linearis, Dichellograptus anceps, D. complanatus, D. truncatus, Leptograptus flaccidus.
- Echinoderma.* Rhaphanocrinus basalis, Echinosphera aurantium, Sphaerionites munitus, S. Litchi, Hemicosmites rugatus.
- Crustacea.* Agnostus trinodus, Trinucleus concentricus, T. seticornis, Illæus Davisi, I. Bowmanni, Homalonotus bisulcatus, Phacops apiculatus, P. Brongniarti, Lichas laxatus, L. hibernicus, Staurocephalus globiceps.
- Bryozoa.* Monticulipora favulosa, M. petropolitana, Phyllopora Hisingeri, Ramipora hochstellersi.

Orthis vespertilio *Trinucleus concentricus* *Orthis calligramma*

Fig. 30.—THREE BALA FOSSILS.

- Brachiopoda.* Orthis actoniæ, O. flabellulum, O. calligramma, O. bifurcata, O. hirsutensis, O. vespertilio, Leptæna (Plectambonites) sericea, Strophomena expansa, S. siluriana, Trematis corona.
- Lamellibranchia.* Ctenodonta varicosa, Palæarca edmondiiformis, Modiolopsis obliqua, M. expansa, M. modiolaris.
- Gastropoda.* Holopea concinna, Cyclonema crebristria, Murchisonia simplex, Ecculiomphalus Bucklandi, Tentaculites anglicus, Hyolithes (Theca) triangularis, Bellerophon nodosus.
- Cephalopoda.* Cyrtoceras sonax, Orthoceras vagans, Trochoceras cornuarietis.

C. BRITISH ORDOVICIAN ROCKS

Ordovician rocks occupy much larger areas of the surface in Great Britain than the Cambrian rocks, and are also found in several parts of Ireland. In Wales they occupy nearly all the western and central portions of the country, outside the Cambrian outcrops. They pass eastward beneath the overlying Silurian strata, and portions of them emerge again in Shropshire and Radnorshire.

Rocks of this age occupy a large part of the Lake District, where they were first studied by Sedgwick. The Isle of Man is an isolated fragment of this Cumbrian area, while to the eastward, in Yorkshire, some small exposures occur, proving the extension of Ordovician rocks beneath the newer strata in that direction.

In the south of Scotland, Ordovician and Silurian rocks range across from Wigtown to Berwickshire, and form the mass of the Southern Highlands, their northern boundary being generally the great line of fault which runs from Girvan in Ayr to the Lammermuir Hills.

Ordovician rocks occur in many parts of Ireland and exhibit several different facies, one of these facies being found in the north-west (Galway, Mayo, Donegal, and Londonderry), another in the north-east (Down, Cavan, and Meath), another in the south-east (Wicklow, Wexford, and Waterford, with extensions into Clare and Tipperary).

In most places the Ordovician rocks seem to succeed the Cambrian in conformable sequence, but in North Wales there appears to be a decided break of continuity, the basal grit of the Arenig Series lying unconformably on the Cambrian and passing transgressively across the members of the Tremadoc Series on to those of the Ffestiniog Group. From an examination and survey of the country around the Arenig and Aran Mountains Mr. Fearnside has expressed his belief that the Cambrian rocks of North Wales were ridged up into a series of low flexures striking north and south before the deposition of the Arenig sediments.⁵ This physical disturbance was probably due to the intense volcanic action which shortly afterwards led to the establishment of surface volcanoes, and to the outpouring of the great masses of lava and ashes which are such conspicuous features in the Ordovician Series of Merioneth and Carnarvonshire.

1. *Wales*

Arenig Series.—The typical district of this group is supposed to be that of the Arenig Mountains in Merioneth; but the series as now restricted is not there very thick, and it will be more convenient to begin with South Wales, Pembroke, and Carmarthen, where it has a fuller development.

The outcrop of the Arenig Series on Ramsey Island and round St. David's Head is shown on Fig. 16, p. 80. From the latter point its outcrop runs eastward and curves round the St. David's anticline to near Haverfordwest, and thence eastward to Carmarthen and Llangarthney.

Dr. H. Hicks described the Lower Arenig, near St. David's, as consisting of fine black slates and shales, which are best exposed in Ramsey Island, where they have yielded *Didymograptus extensus*, *Phyllograptus stella*, *Trigonograptus ensiformis*, and *T. truncatus*. They also contain *Ogygia scutatrix* and *Asaphellus homfrayi*. Some of the same beds are seen in Whitesand Bay on the mainland, but are faulted against the Tremadoc slates. He believed this group to be about 1000 feet thick.

What must be called the Upper Arenig (Middle Arenig of Hicks) are a series of black slates and flagstones with some beds of gritty sandstone, and they have yielded many of the characteristic Arenig trilobites, *Ogygia peltata*, *Aeglina grandis*, *Trinucleus Gibbsi*, and *Ampyx Salteri*, and the graptolites *Tetragraptus serra*, *T. crucialis*, and *Didymograptus patulus*. These beds are about 1500 feet thick.

The equivalents of this series have recently been mapped in Carmarthenshire for the Geological Survey by Messrs. Cantrill and H. Thomas, who have termed them the *Tetragraptus Beds* and have divided them into two stages or zones, (1) that of *Didymograptus extensus*, (2) that of *Did. hirundo*. The former includes the greater part of the series, and is over 1000 feet thick; lithologically it consists of blue-black shales and mudstones with grits and conglomerates at the base which mark it off from the underlying Tremadoc slates. The upper zone appears to be only about 200 feet thick.

North of Carmarthen the Arenig Series passes under the flexured mass of higher Ordovician rocks which occupy the central area of Wales (Cardigan, Brecknock, and Montgomery), not again coming to the surface till brought up by the great Harlech or Merionethshire anticline. Round this it forms a nearly continuous outcrop from Towyn on the coast through the Cader Idris, Aran, and Arenig ranges, and thence through the Migneint district to Manod Mawr, north of Ffestiniog (see Fig. 19), where it seems to be faulted against higher beds. Throughout this tract of country from Cader Idris to the Arenig Mountains, the place of the Arenig Series appears to be entirely below the beds of volcanic ash and the intrusive masses of andesite which were formerly included in this series. In the district of Arenig Fawr and Moel Llyfnant the succession of beds has been mapped and described by Mr. Fearnside,⁶ and the position of the Arenig Beds is shown in the section drawn by him and reproduced by his permission in Fig. 31. The series here is only about 600 feet thick, but both zones can be recognised, and the sequence is as follows:—

N.W.

[Scale:-3 inches=1 mile.]

Fig. 31.—SECTION FROM CRAIG WEN TO THE TOP OF ARENIG FAWR.

- 3, 4, 5. Volcanic ashes (*Llandilo*).
- 6. Daerfawr shales (*D. Murchisoni*).
- 7. Volcanic ash and agglomerate.
- 8. Oletha shales (*Z. of D. bifidus*).

- 9, 10. Zone of *Did. hirundo*.
- 11. Calcareous ashes.
- 12. Llyfiant flags (*D. exiensis*).
- 13. Basal grit (of Arenig).

- 14, 15, 16. Trenadoc Beds.
- 17-20. Dolgelly Beds.
- 21, 22. Ffestiniog Beds.
- 23, 24, 25. Intrusive igneous rocks.

	Feet.
5. Dark calcareous shales with <i>Didymograptus hirundo</i> and <i>Tetragraptus serra</i>	200
4. Erwent or <i>Ogygia</i> limestone, yielding <i>Ogygia Selwyni</i> , <i>Orthoceras sericeum</i> , <i>Monobolina plumbea</i> , etc.	20
3. Henllan ashes—hard, grey, compact beds with <i>Calymene parvifrons</i>	150
2. Llynant flags with <i>Did. extensus</i> and <i>D. deflexus</i>	200
1. Basal grit, varying in thickness from	0 to 100

About 620

On the north side of the Harlech anticline the series is found in the Moelwyn Mountains, north-west of Ffestiniog, the basal grit being there overlain by 800 feet of hard spotted flagstones in which only a species of *Tetragraptus* has yet been found. The limestone is absent, and the *Did. hirundo* shales seem to be represented by bands of slate intercalated with thick beds of volcanic ash and agglomerate.

Westward the basal grit has been found above the Tremadoc Series, but the overlying beds are so broken by faults that no succession can be made out. They come in again in the southern part of the Llyn peninsula where grits and flags with extensiform graptolites pass across the edges of the Lingula flags and rest on the Archæan rocks near Aberdaron. On the eastern side these beds are overlain by a band of grit and breccia 60 to 70 feet thick containing fragments of schist, granulite, etc., derived from the Archæan rocks, and this is succeeded by dark shales which have yielded *Didymograptus hirundo*. Above them are beds of ironstone and manganese-ore with blue mudstones containing *Azygograptus suecicus*.

Arenig slates also form part of the great slate country in Carnarvonshire north-west of the Snowdon range, but the details of this area have not yet been worked out. The complete series has, however, been indicated by Miss G. L. Elles⁷ along the banks of the river Seiont at Carnarvon, where the zone of *D. extensus* consists of calcareous flags and shales containing that species with *Azygograptus suecicus* and *Eglina binodosa*. To the south of these beds are micaceous flags and shales yielding *D. hirundo*, *D. nitidus*, and numerous phyllopoas, and these are succeeded by black shales with a Llanvirn fauna. The outcrops extend for a distance of about 2000 yards with a dip of from 40° to 50° to the south-east, and the series seems therefore to be about 1400 feet thick.

Arenig Beds have also been recognised on both sides of the Menai Strait, but in Central Anglesey they are believed to have thinned out and to be overlapped by the Llanvirn Beds.

Fig. 32.—SECTION FROM MENAI STRAIT ACROSS THE SNOWDON RANGE AND THE HARLECH ANTICLINE. Distance about 30 miles.

Fig. 33.—SECTION FROM THE ARENIG TO THE BERWYN MOUNTAINS. Distance about 24 miles.

The lower section is practically a continuation of the upper one.

Llanvirn Series.—This group was separated from the beds below and above it by Dr. Hicks in 1881. It takes its name from that of a village near Llanrain in Pembrokeshire (see map, Fig. 16), where the slates have yielded many of the characteristic trilobites and graptolites of the Lower Llanvirnian or zone of *Didymograptus bifidus*. This species and its congeners *D. artus*, *D. nanus*, and *D. Murchisoni* are often termed the tuning-fork graptolites, as distinguished from the extensiform species which prevail in the underlying Arenig Beds.

The lower stage is probably from 1200 to 1500 feet thick in Pembrokeshire, and consists of dark-grey flags and slates. The upper stage or zone of *D. Murchisoni* consists of fine black slates interbedded with felspathic tuffs and has a thickness of about 500 feet.

These beds have now been mapped by the Geological Survey from Haverfordwest eastward, through Narberth and Carmarthen. Along this tract the lower stage maintains its thickness, but the *Murchisoni* Beds are much reduced, being only 230 feet near St. Clears, while east of Carmarthen they appear to thin out below the base of the overlying Ffairfach Grit (Llandilo).

Passing now to Merioneth there is no doubt that the Llanvirnian can be followed all round the great Harlech geanticline, but they have not yet been separated from the Arenig and Llandilo Series. Their position on Arenig Fawr is indicated in Mr. Fearnside's section (Fig. 31, p. 118), the base being marked by a band of shale with *D. bifidus* which is overlain by a volcanic series consisting of ash and agglomerate with thick intrusive masses or laccolites of hypersthene-andesite. Above these, however, is an outcrop of shale containing *Diplograptus foliaceus* and other species which suggest a high horizon in the *Murchisoni* zone.

The position of the Llanvirnian in the Maelwyn area has not yet been ascertained, but farther west in the promontory of Penrhyn (see Fig. 20), it appears to be faulted down against the basal Arenig grit, for the black slates of Ty Obrey which adjoin that grit have yielded fossils which prove them to be of Llanvirn age. Above them are ashy slates and ash beds passing under a thick volcanic series.

In Carnarvon the Llanvirn Series has not yet been separated as a stratigraphical division from the beds above and below, but as mentioned on p. 119, the *bifidus* zone has been recognised as succeeding the *hirundo*-beds on the river Seiont near Carnarvon.

Its existence in Anglesey has a special interest, because in the central part of that island it forms the base of the Ordovician System, and has a basal conglomerate which rests directly on the

Archæan rocks. The lowest horizon from which fossils have been obtained are sandstones overlying the basal conglomerate near Llanfaelog (see Fig. 34). These fossils are an *Orthis* resembling *O. Carausi* and fragments of a trilobite regarded by Professor Hughes as a *Nesuretus*, but the specimen is probably *Calymene Tristani*, while the slates which succeed the sandstones contain graptolites of Upper Llanvirn species. Moreover, as Dr. Matley has pointed out, there is a complete absence both in Central and Northern Anglesey of the characteristic Arenig graptolites.⁸ He therefore infers that the lowest fossiliferous rocks in Central Anglesey are equivalents of the beds now classed as Llanvirnian, while in the north of the island even these do not appear, and must have been overlapped by the Bala Series.

Fig. 34.—SECTION WEST OF LLANFAELOG (DR. H. HICKS).

Scale 6 inches to a mile.

6. Blown sand.	3. Basal conglomerate (? Ordovician).
5. Black slates and dark flags.	1. Granitoid Series.
4. Flagstones and sandstones.	

Llandilo Series.—The typical area of these beds and the place from which they take their name is Llandilo in Carmarthenshire, where the series originally described by Murchison as the “Llandilo flags” forms a natural group, well marked off, both in regard to its lithological characters and its fossil contents, from the underlying Llanvirn Series. Hence the Geological Survey have recently found it necessary (as already stated) to adopt the latter series as a primary division and to restrict the Llandilo Series within its original limits.⁹

Near Llandilo and north-eastwards to Llangadock the group consists mainly of grey calcareous flagstones weathering to a yellowish brown. These are about 2500 feet thick, and in their lower part they contain many beds of hard bluish-grey limestone, most of them being fossiliferous and yielding both *Ogygia Buchi* and *Asaphus tyrannus*. Under these beds is a hard massive calcareous grit, the Ffairfach grit, which has a thickness of about 150 feet and also contains *Asaphus tyrannus*.

When traced westward, however, this grit thins out and its place is taken by a band of volcanic ash, while the upper part of the flagstone series passes into black shale, the whole at the same time greatly diminishing in thickness, so that near Carmarthen the group is less than 900 feet thick and the succession is:—

	Feet.
Hendre shales with <i>Dicellograptus divaricatus</i>	500
Llandilo flags and limestones	about 250
Volcanic ash with <i>Asaphus tyrannus</i>	about 70

Still farther west the “*Asaphus ash*” also thins out, and the flaggy limestones are condensed into one band of dark grey or black limestone which rests directly on the Llanvirnian shales.

On the north side of the St. David’s anticline the series has again become much thicker and is divisible into two stages as below:—

	Feet.
Black slates and flags with <i>Ogygia Buchi</i> and <i>Calymene duplicata</i>	1000
Calcareous flags and limestone with <i>Asaphus tyrannus</i> and <i>Calymene cambrensis</i>	about 800

The restricted Llandilo Series has not yet been mapped either in Merioneth or Carnarvonshire. The upper andesitic and rhyolitic ashes of the Arenig Mountains are regarded by Mr. Fearnside as belonging to this series, and they are unconformably overlain by a fossiliferous limestone which seems to belong to the Bala Series. In the anticline of the Berwyn Mountains to the eastward Llandilo Beds appear again with a more normal facies, having a band of limestones at or near the base which are about 400 feet thick and are full of such fossils as *Asaphus tyrannus*, *Calymene cambrensis*, *Orthis turgida*, etc.

In the Snowdonian district there is a great development of volcanic rocks which were included by Ramsay in the Bala Series, but are now thought to be largely of Llandilo age; for upon the highest volcanic rocks of Snowdon rest black shales crowded with species of *Diplograptus* which seem to indicate a low horizon in the Bala Series.

The lavas and ashes of the Snowdon range seem to have issued from a group of volcanic vents which probably formed volcanic islands in the Ordovician sea. Near the actual centres of eruption both ashes and lavas are found, the latter being usually rhyolites, but in other localities, presumably more distant from the volcanic vents, ashes are the prevalent deposit, and these are interstratified with some bands of slaty shale. This volcanic series extends to the very northern extremity of Carnarvonshire.

Bala Series.—In Pembrokeshire this series was described for the first time in any detail by Messrs. Marr and Roberts in 1885.¹⁰ They examined the succession of beds near Haverfordwest and Narberth, and established divisions which have been adopted by the Geological Survey officers, who have since mapped the beds through Pembroke and Carmarthen, and have at the same time fixed the horizon of passage between the Llandilo and Bala Series in this area.

The limestones are seldom all developed in one locality, being lenticular beds which thin out entirely in some directions, but when each occurs it is on the same horizon and the complete succession is given as follows :—

		Feet.
Ashgillian	{ Slade and Redhill Beds	2000
	{ Sholeshook limestone	up to 200
Caradocian	{ Robeston Wathen limestone	100
	{ Mydrim shales with <i>Dicranograptus</i>	500
	{ Mydrim limestone	0 to 150
		<hr/> About 2900

The Mydrim limestone is quite local, and in its absence the horizon can only be distinguished by the change in the species of graptolites, the lower part of the Mydrim shales being characterised by *Dicranograptus Nicholsoni*, the middle part by *Mesograptus multidentis*, *Dicranograptus Clingani*, and *Diplograptus calcaratus*; while the uppermost 100 feet yield *Diplograptus truncatus* and *Climacograptus minimus*.

The overlying limestones are most fully developed near Narberth, the lower beds consisting of fairly pure limestone, black in tint and crowded with corals of the genera *Heliolites*, *Halysites*, and *Favosites*, with many Brachiopods, but few trilobites. The Sholeshook limestone has quite a different assemblage, being grey or greenish in colour, impure and sandy in texture, and characterised by an abundant trilobite fauna including *Staurocephalus globiceps*, *Trinucleus seticornis*, *Phacops Brongniarti*, and *Cheirurus juvenis*, with many Cystideans, Gastropoda, and Cephalopoda.

The overlying beds form a monotonous series of bluish-grey mudstones which are only fossiliferous on certain horizons; they sometimes include bands of limestone containing *Favosites fibrosus* and sometimes more sandy beds which contain many species of *Orthis*, while the shales contain *Leptæna sericea*.

Northward this Bala Series extends over a considerable area, and probably occupies large parts of Central Wales, along the anticlinal axes of the numerous flexures into which the rocks of that region have been folded, but little information about them is at present available.

In North Wales they are typically developed near Bala, but the base of the series has not yet been determined by graptolitic evidence. There is a great thickness of sandy shales below the Bala limestone, and some portion of them is probably of Bala age, but the greater part of the Lower Bala Group of Sedgwick is now regarded as Llandilian.

The beds which have been grouped as Bala limestone include two distinct horizons or zones; and the name Bala limestone is now restricted to the lower of these zones, the Rhiwlas limestone, which was formerly exposed at Rhiwlas, north of Bala, being the equivalent of the Sholeshook limestone in Pembrokeshire.

Even the main mass of the Bala limestone is often split up into several beds by the intercalation of calcareous sandstone or shale,

Fig. 35.—SECTION THROUGH THE BALA LIMESTONE NEAR GELLYGRIN,
SOUTH OF BALA LAKE (Ruddy).

8. Shales with *Leptaena sericea*.
7. Coarse sand, many fossils.
6. Crystalline limestone.
5. Coarse sand like No. 7.

4. Sandy shales, trilobites.
3. Sandy limestone, brachiopods.
2. Volcanic ash.
1. Shales with *Orthis*.

as at Gellygrin, to the south of Bala Lake, as described by Mr. T. Ruddy.¹¹ Here there is a lower limestone, 12 feet thick and containing many fossils, succeeded by sandy shales with many of the characteristic Bala trilobites, and some feet higher a hard, massive, crystalline limestone 18 or 20 feet thick, the whole group of beds (5 to 8 in Fig. 35) being about 50 feet thick.

The characteristic fossils of the Bala limestone are *Trinucleus concentricus*, *Asaphus Powisi*, *Phacops apiculatus*, *Homalonotus bisulcatus*, *Orthis vespertilio*, *O. spiriferoides*, and *O. biforata*. Those of the Rhiwlas limestone are *Cyrtoceras sonax*, *Orthoceras vagans*, *Trinucleus seticornis*, *Ampyx tumidus*, *Encrinurus sexcostatus*, *Staurocephalus clavifrons*, *Phacops Brongniarti*, *Leptaena tenuicincta*, *Sphaeronites Litchi*, *Echinospæra aurantium*, *Hemicosmites rugatus* and other cystid Echinoderms.

Above this limestone there is some 1500 feet of sandy shale, the upper beds of which contain graptolites of Silurian (i.e. Llandovery) species. The exact horizon at which the divisional line should be drawn has not yet been ascertained, but the thickness of Upper Bala Beds is probably not less than 1000 feet.

From the above account it will be seen that the succession in the typical Bala district may be summarised as below :—

		Feet.
Upper	{ Grey shales and shaly sandstones	about 1000
Bala	{ Rhiwlas limestone	10 to 20
Lower	{ Bala limestone	10 to 50
Bala	{ Grey sandy shales	perhaps 1600
		<hr/> About 2600

The succession in the Berwyn Mountains to the eastward has been described by Mr. D. C. Davies, and more recently by Messrs. Groom and Lake.¹² From the account given by the latter of the series exposed near Glyn Ceiriog, it appears that a great thickness of beds (the Paudy Series) below the Bala limestones must be included in the Bala Series. These beds consist of volcanic ashes, sandstones, and slates, and some of them contain many of the characteristic Bala fossils; their total thickness being about 1600 feet. In the Ceiriog district the true Bala limestone appears to be faulted out, but elsewhere there is from 200 to 300 feet of such limestone, containing the usual trilobites, brachiopoda, and corals. Above this are calcareous shales and bands of limestone containing the fauna of the Rhiwlas beds. These are succeeded by shales of a considerable thickness.

To the north and north-west of the Bala district the limestones appear to thin out or to pass into a nodular calcareous tuff. In the Lleyrn peninsula the place of the Bala Series is occupied by a thick set of sandy shales and mudstones of an olive-green colour, and including thin beds of felspathic grit which are largely made up of volcanic detritus.

The Bala Series can be traced northward to Conway, and the succession near that place has been described by Miss G. L. Elles,¹³ who has divided the beds into the following groups :—

	Feet.
Deganwy mudstones	80
Bodreida mudstones or Trinucleus Beds	350
Cadnant shales { Upper, shales with <i>Orthograptus truncatus</i> Lower, flags with <i>Mesograptus multidens</i> , <i>Climaco-</i> <i>graptus</i> , and <i>Dicranograptus</i> }	310
Conway Mountain Volcanic Series	over 2000

Miss Elles regards the Lower Cadnant shales as Llandilian, but almost all the species of graptolites recorded by her from these beds occur also in the Mydrim shales of Carmarthen, and as the total thickness of the sedimentary beds at Conway is only 740 feet, it is probable that the base of the Bala Series is to be found in the volcanic rocks.

2. Shropshire

As the Ordovician Series of South Shropshire is a continuation of the Welsh facies of the formation, it is unnecessary to give a detailed account of the local subdivisions. For a description of these the student is referred to that given by Professors Lapworth and Watts in *Proc. Geol. Assoc.* vol. xiii. p. 312. Only a brief summary will here be given, with a separation of the Llanvirnian by means of the graptolite zones which Miss Elles has more recently been able to establish.

The Ordovician Series is brought up to the surface in Shropshire by the broad compound geanticline, of which the Longmynd may be regarded as the central axis (see map, Fig. 21, and section, Fig. 7). The principal area of Ordovician rocks is on the western side of the Longmynd, around Shelve and Corndon, where the general dip is westward, and the whole succession is found from Arenig to Upper Bala. On the eastern side (Caradoc area) the outcrop is narrow and only equivalents of the Bala Series occur, resting directly either on Archæan or on Cambrian rocks. From this disposition it is evident that all the lower members of the Ordovician System thinned out against the shores of a land-area consisting of the older rocks, and that this land did not sink below the Ordovician Sea until the beginning of Caradocian time.

Arenig Series.—The base of this division consists of a hard siliceous grit or quartzite forming the ridge called the Stiper stones; above this are grey and green flagstones with interbedded shales, in which Professor Lapworth has found *Ogygia Selwyni*, *Tetragraptus quadribuchiatus* with species of *Phyllograptus* and *Trigonograptus* which mark them as Lower Arenig. In the higher part of the series both *Didymograptus extensus* and *D. hirundo* have been found, so that probably the whole of the Welsh Arenig is represented and the total thickness may be 1500 feet.

Llanvirn Series.—The Hope shales, which have yielded *Did. bifidus*, form the lower part of this series and are succeeded by hard andesitic tuffs with intercalations of shale which prove the whole to have been deposited in water. These beds are overlain by flags and shales with few fossils, but at the top are the Betton shales with *Didymograptus Murchisoni*. The thickness of this series is probably about 2000 feet.

Llandilo Series.—This is represented by the Meadowtown Beds, a series of flags and flaggy limestones containing *Asaphus tyrannus* and *Ogygia Buchi*, overlain by black mudstones and shales with *Leptograptus flaccidus* and *Nemograptus gracilis*. Their thickness has not been estimated, but is probably about 1000 feet.

Bala and Caradoc Series.—Continuing the above succession in the Shelfe district the Bala Beds are well exposed in the Spy Wood section. At the base are the Spy Wood grits and flags passing up into shales; these beds yield *Trinucleus concentricus*, *Orthis calligramma*, *Diplograptus truncatus*, *Climacograptus bicornis*, and other fossils. Above comes the Marrington Group, a set of grey and black shales with interstratified beds of andesitic ashes and breccias or agglomerates; the highest shales are overlain unconformably by the Silurian (Upper Llandovery Beds), the Hirnant Beds not being exposed.

Fig. 38.—SECTION NEAR HOPE BOWDLER IN SHROPSHIRE (after E. S. Cobbold).

z. Wenlock limestone.	l. Longville flags.	h. Harnage shale.
y. Wenlock shale.	s. Chatwall sandstone.	g. Hoar Edge grits.
w. Llandovery Beds.		

On the eastern side of the Longmynd the succession in the Caradoc district was first worked out by Murchison and formed the type of his "Caradoc sandstone." This was subsequently proved to be only a local facies of the Bala Series. The succession as corrected by Callaway and Lapworth is as follows:—

Llandovery Beds (unconformable)—

Caradoc sandstone, 2000 feet	{	<i>Trinucleus</i> shales.
		Acton shales and limestone.
		Cheney Longville flags.
		Harnage shales.
		Hoar Edge grits and sandy limestone.

All these beds contain fossils, and the Acton Beds have yielded *Lichas laxatus*, *Ampyx*, *Orthis Actonia*, *O. flabellulum*, and many corals, so it is probable that they represent the Bala limestone. The highest or Hirnant Beds are concealed by the overstep of the Silurian.

3. Cumberland and Westmoreland

Ordovician rocks occupy a large area in the Lake District, which was the scene of Professor Sedgwick's earliest work on the

Fig. 39.—MAP OF CUMBERLAND AND WESTMORELAND.

rocks of this system (1832-36). All the mountainous region lying north-west of a line drawn from the estuary of the Duddon by Hawkshead and Ambleside to the valley of the Lowther Beck consists essentially of Ordovician rocks (see the map, Fig. 39, and section, Fig. 37).

They are also found in a long narrow inlier, known as the Cross Fell inlier, on the eastern side of the Vale of Eden in the north-east of Westmoreland, bounded on the one side by Carboniferous limestone and on the other by New Red Sandstone.

The Ordovician rocks of this area are divisible into four series, which are roughly equivalent to those of Wales.

Skiddavian Series.—It was stated on p. 93 that the greater part of the great mass of slates which have generally been known as the Skiddaw slates was of Ordovician age, but as the highest portions belong to the Llanvirnian Series it is only the central portion which is strictly the equivalent of the Welsh Arenig Series, and for this part the name Skiddavian may be used. Its basement beds are certain beds of grit which are called the Watch Hill grits in the memoir of the Geological Survey on the country between Appleby, Ulleswater, and Haweswater (1897).

Above this horizon the slates have yielded both trilobites and graptolites, which have enabled Dr. J. E. Marr and Miss G. L. Elles¹⁴ to recognise three zonal divisions which, however, cannot at present be correlated exactly with those of Wales. They are :—

3. Upper Tetragraptus Beds, yielding *Tetragraptus serra*, *Didymograptus indentus* (var. *nanus*), and *Phyllograptus typus*.
2. Dichograptus Beds, *Dichograptus 8-branchiatus*, and *Did. patulus*.
1. Lower Tetragraptus Beds, with *Tetr. Bigsbyi*.

The whole series is so greatly flexured and faulted that it is impossible to form any accurate estimate of its thickness.

Llanvirn Series.—This is typically developed in the Cross Fell area, where the two well-known components of the series have been distinguished under the names of Ellergill and Milburn Beds respectively; the former being black slates containing *Didymograptus bifidus* and *Glossograptus armatus*, the latter being mainly volcanic rocks (ashes and lavas) interstratified with slates which have yielded *Did. Murchisoni* and *Diplograptus dentatus*.

In the Lake District beds belonging to the lower stage occur near Threlkald and Troutbeck, east of Keswick, and those of the upper stage near Ulleswater and elsewhere.

Llandilo Series.—This consists of an immense thickness of volcanic rocks—rhyolitic and andesitic lavas with thick beds of ash and agglomerate (see map, Fig. 39), which are generally of

green or purple colour. They are the "Green Slate and Porphyry Group" of Sedgwick, afterwards called the Borrowdale Series. Their total thickness is estimated to be 12,000 feet, but not all of this is of Llandilo age; as above stated the lower part is evidently of Llanvirnian date, the central part must be Llandilian, and the highest part may be of Bala age; for in the Lake District the volcanic series is directly succeeded by the Coniston limestone, but in the Cross Fell inlier there are stratified beds containing Bala fossils between the limestone and the highest rhyolite of that area.

Bala Series.—The thickness of the stratified portion of this series, even including those of Roman Fell, is much less than the corresponding beds in Wales (*i.e.* about 300 feet), but a regular zonal succession can be made out. The series has been subdivided by Dr. Marr¹⁵ as follows:—

	Coniston area.	Cross Fell area.
Ashgillian	{ Shales.	Ashgill shales.
	{ Staurocephalus limestone.	{ Keisley limestone.
	{ Applethwaite limestone.	
Sleddale Beds	{ Conglomerate.	
	{ Stile End Beds.	{ Dufton shales.
Roman Fell Group—	Rhyolite.	Corona Beds.

The "Corona Beds" are a set of calcareous shales, limestones, and ash beds, about 100 feet in thickness, and they contain many brachiopods, such as *Trematis corona*, *Lingula tennigranulata*, *Orthis testudinaria*. The limestones consist largely of the tests of a small Crustacean called *Beyrichia*.

The Applethwaite limestone consists of calcareous shales with bands of limestone and a peculiar bed of white horny limestone at the top. Overlying this is a bed of grey limestone about 5 feet thick which contains the fauna of the Rhiwlas and Sholeshook limestones, *i.e.* many Cystidean Echinoderms with *Staurocephalus clavifrons*, *Phacops apiculatus*, and *Orthoceras vagans*.

The limestones are succeeded by dark blue and grey shales which yield many of the same fossils that occur at similar horizons in North Wales.

4. Scotland

The southern uplands of Scotland are largely composed of Ordovician and Silurian rocks folded together into a number of anticlinal and synclinal folds, each fold having its subsidiary plications, so that the country has a complicated structure, and can only be successfully mapped by careful attention to fossils. The older views about this region were mistaken because the fossils were not sufficiently studied, and because it was supposed that

Fig. 40.—SECTION ACROSS LANARKSHIRE AND DUMFRIESHIRE FROM CAIRN TABLE TO LANGHOLM (after Professor Lapworth). Distance about 50 miles.

8. Lower Carboniferous.
7. Old Red Sandstone.
6. Riecarton Group.
5. Gala Group.
4. Birkhill shale.
3. Hartfell shales.
2. Glenkiln shales.
1. Ballantrae Group (Arenig).

Fig. 41.—SECTION THROUGH THE MOFFAT DISTRICT (from Professor Lapworth's paper in the *Quart. Journ. Geol. Soc.*). Distance about 6 miles. References the same as to Fig. 40.

graptolites were characteristic of Llandilo Beds and did not occur outside their limits. The true structure and succession of strata in this region was first established by Professor Lapworth, whose researches on the Girvan and Moffat districts are embodied in two detailed papers, and who afterwards summed up the structure of the whole region in another one, to which the student should refer.¹⁶ More detailed descriptions are given in the "Geology of the Southern Uplands," *Mem. Geol. Surv.* 1899. The sections, Figs. 40 and 41, are taken from Lapworth's papers.

The special interest of this region is that it presents us with two very different facies of sedimentation, which, however, can be traced through changing intermediate facies from the one area to the other. In Ayrshire (Girvan, etc.) the Ordovician has the ordinary facies of a formation accumulated at no great distance from a continental coast-line, consisting as it does of a considerable thickness of conglomerates, sandstones, shales, with at least one bed of limestone. The other type, found in Dumfries and Wigtownshire, is one that must have been formed in much deeper water, for there the whole system is condensed into a small thickness of dark-coloured mudstones, shales, and chert-beds. The base of it is not exposed, but the total thickness from the summit of the Bala Series down to the base of the Arenig chert-beds is only about 185 feet, as compared with a thickness of 3500 feet in Girvan.

Professor Lapworth divided the Ordovician of this region into three groups or series, which are roughly equivalent to Arenig, Llandilo, and Bala, and these divisions have been adopted by the Geological Survey of Scotland. The graptolitic facies of the formation lends itself to easy zonal subdivision and to correlation with other areas, so that the names given to the middle and upper parts of this succession, *i.e.* Glenkiln shales and Hartfelt shales, have been widely used as if they were synonymous with Llandilo and Bala. The progress of discovery in Wales, however, has shown that the divisional line between the Glenkiln and Hartfelt shale is not quite on the same horizon as that taken in South Wales between the Llandilo and Bala.

Moreover, nothing comparable to the Llanvirn Series has yet been identified in Scotland. No shales yielding *Didymograptus bifidus* or *Did. Murchisoni* have been found. In the one area there is a distinct unconformity at the base of the Llandilo with a conglomerate above the break; in the other there is merely an abrupt change from one kind of sediment to another. It is evident, however, that a chapter of the geological record is missing in this region, and the following tabular view gives the established divisions without any attempt to correlate them with those of Wales.

Girvan District.

Moffat District.

Ardmillan Series, 2600 feet (Bala).

- DRUMMUCK BEDS, 400 feet—
 b. Shales with *Staurocephalus*.
 a. Shales with *Trinucleus seticornis*.
 SHALLOCH FLAGS, 800 feet—
 Flagstones and shales with *Dicellograptus truncatus*.
 WHITEHOUSE BEDS, 300 feet—
 b. Beds with *Dicellograptus complanatus*.
 a. Beds with *Leptogr. flaccidus*.
 ARDWELL FLAGS, 1000 feet—
 b. Beds with *Dicrano. ramosus* and *Diplograptus rugosus*.
 a. Beds with *Crypto. tricornis* and *Diplograptus foliaceus*.
 BALCLATCHIE BEDS, 100 feet—
 Grits and sandstones with *Climacograptus bicornis* and *Cryptogr. tricornis*.
 Shales with *Glossograptus Hincksi*.

Barr Series, 800 feet.

- BENAN CONGLOMERATE, 500 feet.
 STINCHAR GROUP, 100 feet—
 b. Shales with *Didymograptus superstes* and *Dicellograptus sextans*.
 a. Limestones with *Maclurea Loganii*.
 KIRKLAND BEDS, 200 feet—
 Sandstones and conglomerates with *Orthis confinis*.
 Unconformity here.

Arenig Series, 1500 feet.

- RADIOLARIAN CHERTS, red and grey cherts, mudstones, and volcanic tuffs, 70 feet.
 Black shales of Bennane Head with *Tetragraptus quadribrachiatus*, 4 feet.
 VOLCANIC ROCKS, lavas and tuffs with thin shales containing *Tctr. quadribrachiatus*, 1500 feet seen.

HARTFELL SHALES, 100 feet—

6. Zone of *Dicellograptus anceps* and *D. truncatus*.
 5. Barren mudstones.
 4. Zone of *Dicello. complanatus*.
 3. Zone of *Pleurograptus linearis* and *Lepto. flaccidus*.
 2. Zone of *Dicranograptus Clingani* and *D. ramosus*.
 1. Zone of *Climacogr. Wilsoni* and *Cryptogr. tricornis*.

GLENKILN SHALES, 50 feet—

- Black shales with *Didymograptus superstes*, *Dicel. sextans*, and *Diplograptus dentatus*.
 Yellow mudstones with chert-bands.
 Black shales with *Canograptus gracilis* and *Didymograptus superstes*.

RADIOLARIAN CHERT BEDS—

- Mudstones and shales with layers and lenticular nodules of chert, 150 to 200 feet.
 Volcanic tuffs at Trowdale, 150 feet. Base not seen.

Arenig Series.—From this table it will be seen that so far as the beds are exposed the greater part consists of volcanic rocks, but that the highest member is a group of mudstones and shales interstratified with lenticular layers of red and grey chert which are full of the remains of Radiolaria. From this fact it has been inferred that these beds were oceanic deposits formed under a great depth of water and at a great distance from land. Elsewhere, however, I have shown that such an inference cannot be drawn from the mere occurrence of Radiolaria (see *Building of the British Isles*, 3rd edition (1911), pp. 12 and 72).

The narrow compass, within which the beds representing the Ordovician System are compressed in the Moffat district, is shown in Fig. 42, which is reduced from a section in the Survey Memoir.

Fig. 42.—SECTION THROUGH TROWDALE IN THE URR VALLEY.
(Scale about 750 feet to an inch.)

Silurian { 6. Gala Beds. Ordovician { 4. Hartfell shales. 2, 1. Chert Beds and
5. Birkhill shales. 3. Glenkiln shales. Volcanic tuffs.

In the **Barr Series** the Stinchar limestone is an interesting horizon, for many of its fossils are not found anywhere in England, but occur in the Trenton limestone of North America; such are *Maclurea Logani*, *M. magia*, *Murchisonia angustata*, the sponge-like coral *Tetradium*, and *Saccamina Carteri*; there are also many corals (*Lyopora favosa*, etc.) and brachiopods, with *Lichas sexcostatus*? *Illenus latus*, *I. Bowmanni*, and *Calymene Blumenbachii*, most of which range from Upper Llandilo to Bala Beds.

The Balclatchie Beds are included in the Barr Series by Professor Lapworth, but he speaks of them as forming a transitional band or zone, and many of the graptolites range into the Hartfell shales. Messrs. Peach and Horne place these beds in the Ardmillan or Bala Series, but leave the Benan conglomerate in the Barr Series. It is possible that the plane of divisions should be drawn between the Balclatchie shales and the overlying grits.

The Ardmillan Series, which is the equivalent of the Welsh Bala Beds, consists of a great thickness of alternating flagstones,

sandstones, mudstones, and shales. It is interesting to note that near the top of the highest (Drumuck) group there is a thin bed of grit which has yielded *Staurocephalus globiceps*, *Trinucleus Bucklandi*, a species of *Paleaster* and other fossils, associated with shales containing *Dicellograptus anceps* and *Diplograptus truncatus*. The graptolites show that these beds are equivalent to the highest part of the Hartfell shale, but there are no limestones comparable with those of Bala and Coniston.

Beds of the Moffat type, dark shales and mudstones, have been traced all across Southern Scotland, from the Lammermuir Hills through the northern parts of Selkirk and Dumfries and the central parts of Kirkcudbright and Wigtown. Beds of an intermediate type form a broad belt to the north of this, varying from 5 to 15 miles in width, from the Moorfoot Hills to the northern part of Wigtownshire.

No deposits of Ordovician age have yet been proved to exist in the Central or Northern parts of Scotland. The only rocks which may possibly be of that age are the green igneous rocks, green shales, and jasper beds which occur between lines of fault along the southern border of the Central Highlands; but these are now believed to be Upper Cambrian (see p. 97).

5. Ireland

Ordovician rocks occur in several parts of Ireland, as will be seen by a reference to the map in Chapter IX.; and they must originally have been deposited over nearly the whole of the Irish region. The largest area is that which spreads through Waterford, Wexford, Wicklow, and Kildare, and is penetrated by the large granitic massif which occupies so much of Carlow and Wicklow. The sediments of this area have much resemblance to those of Wales, and may be regarded as a continuation of the latter, but they are much more altered by subsequent igneous intrusions and by concomitant earth pressures, so that they are greatly plicated, crushed, and cleaved.

The tract in the north, extending from Down to County Cavan, presents a facies similar to that of the condensed series of Southern Scotland, and the same type of graptolitic shale recurs in the south-west round Lough Derg on the borders of Clare and Tipperary. In the north-west, however (Galway and Mayo), there is a very different set of beds of a more littoral character.

Eastern Facies.—The eastern parts of this area were revised by Messrs. Egan and M'Henry of the Geological Survey during the years 1898 and 1899.¹⁷ They found that there was apparently

a conformable passage from the Cambrian into the Ordovician, though the beds along the line of junction are everywhere so mingled together by subsequent plication and crushing that no definite boundary could be drawn between them. The lowest Ordovician Beds are a set of banded slates and fine grits which are generally known as the Ribband Series. They have yielded fossils near Arklow, Courtown, and Kilrea, which included species of *Tetragraptus*, *Phyllograptus*, and *Didymograptus*, and a *Bryograptus* like *Kjerulfi*. Hence they appear to represent a Tremadoc horizon as well as the Arenig and Llanvirn Series.

Above the Ribband Series are black slates which contain a graptolite fauna of Llandilo age, *i.e.* *Dicranograptus Nicholsoni*, *D. ramosus*, *Cenograptus gracilis*, *Diplograptus mucronatus*, and

FIG. 43.—SECTION ACROSS THE CHAIR OF KILDARE (Reynolds and Gardiner).

Horizontal scale, 6 inches to a mile.

Leptograptus flaccidus. These beds are succeeded by shales and limestones of Bala age which have yielded many fossils.

At Portraine, on the coast north of Dublin Bay, there is a small inlier of Ordovician, and the cliffs show an interesting section of Bala deposits. The succession has been described by Messrs. Gardiner and Roberts,¹⁸ and consists of the following; (1) andesitic lavas, (2) coarse ashy conglomerate, (3) calcareous ash beds with layers of limestone and shale, (4) limestones full of corals, (5) compact grey limestone with many trilobites and brachiopods, including *Illenus Bowmanni*, *Staurocephalus sp.*, *Trinucleus seticornis*, and *Sphærexochus mirus*. Thus it appears that after a series of volcanic eruptions in the near vicinity, the water became clear and suitable for the growth of corals, which produced layers and beds of coralliferous limestone, but nothing at all resembling a coral reef. Some change then occurred, probably subsidence, causing a deepening of the water, in consequence of which the corals died out, and their place was taken by trilobites and brachiopods, whose remains are the chief components of the upper limestone.

A more extensive exposure of the series is found in another inlier

among the Carboniferous rocks of Kildare. The succession there is shown in Fig. 43, reproduced by permission of Messrs. Reynolds and Gardiner¹⁹ who have described the rocks seen. All the beds belong to the Bala Series, and have a thickness of about 2200 feet, the main limestone being about 550 feet thick, and containing many trilobites and brachiopods; the fauna is that of the Bala limestone, nor do the overlying shales yield Ashgillian species, though beds of a higher horizon may be present.

Northern Facies.—In the counties Down, Armagh, Monaghan, and Cavan the thickness of the Ordovician Beds is reduced to a band of black shales and mudstones exactly resembling those of Moffat and the southern Scottish belt. Many years ago, from exposures south of Belfast Lough, Mr. Swanston obtained all the characteristic graptolites of the Glenkiln and Hartfell shales. There are also some narrow inlying anticlinal exposures among the neighbouring Silurians, and in one of these near Slane (County Meath) Mr. M'Henry has found some layers of banded Radiolarian chert and dark shales yielding Lower Llandilo or Arenig graptolites.²⁰

The main band of Ordovician runs from north-east to south-west, and in Monaghan and Cavan is from 3 to 9 miles broad. The strata pass north-westward below the Carboniferous rocks, and a portion of them emerges on the southern side of the Archæan ridge near Pomeroy in Tyrone. The Arenig and Llandilo Series appear to have thinned out and to be overlapped by the Bala deposits, which rest directly on the old rocks. The beds are about 350 feet thick and have a conglomerate at the base, overlain by sandstones, flagstones, and mudstones which have yielded a fauna comparable to that of the Drummuck Beds of Ayrshire (Ashgillian); moreover they are conformably succeeded by Silurian strata.²¹

Western Facies.—Ordovician rocks occupy a considerable area on the borders of Mayo and Galway between Killary Harbour and Lough Mask, and there is another tract between Clew Bay and Castlebar. The most complete succession is found in the cliffs and escarpments of the tracts along Killary Harbour. On the south side the lowest beds seen are black shales and cherts about 60 feet thick, containing four species of *Tetragraptus* with *Dichograptus 8-brachiatus*. These beds are succeeded by coarse conglomeratic grits with bands of shale which have yielded *Didymograptus extensus* and *Diplograptus dentatus*; this group is 2500 feet thick, and the grits contain pebbles of red granite and quartz-felsite like those which occur in the Archæan rocks to the north and south.²²

On the south side of the Harbour these grits seem to be

replaced by the Doolough green slates and grits which contain the same graptolites. They pass up into the Mweelrea grits—red and green felspathic grits which in the lower 3000 feet include bands of shale yielding *Ogygia Buchi* and brachiopods, but no graptolites; they are evidently of Llandilian age. In conformable succession is an enormous and monotonous series of reddish felspathic grits, without a single parting of shale and quite destitute of fossils, but they are probably of Bala age. Thus we have the following correlation:—

				Feet.
Bala	{	Mweelrea { Upper	9,000	
Llandilo	{	Grits { Lower	3,000	
Llanvirn	{	Leenane Grits and		
and	{	Doolough Slates	2,500	
Arenig	{	Bencraft shales	60	
	{	Lower beds not seen	at least 500	
				<hr/> 15,000

To the eastward in the Glensaul and Tourmakeady districts a much greater thickness of Arenig Beds is exposed, and they consist partly of coarse grits and conglomerates, partly of a thick mass of volcanic materials, which lower include some fossiliferous beds of limestone and shale. Omitting the felsitic lavas, most of which are intrusive, the succession described by Messrs. Gardiner and Reynolds in this area may be summarised as follows:—²³

	Feet.
Coarse conglomerate and sandstone (very thick)	
Calcareous tuffs, with bands of limestone	? 300
Massive agglomerate of felsite-fragments	750
Volcanic tuffs with a shale yielding <i>Didymograptus hirundo</i> and <i>D. gibberulus</i>	150
Coarse felspathic grits and tuffs	700
Coarse quartzose and some felspathic grits	150
Fine siliceous grits including a black shale with <i>Tetragrapti</i> and cherts containing <i>Radiolaria</i>	150
Coarse grits and conglomerates	seen for over 800
<hr/> 3000	

It will be seen that the base of the Arenig Series is not exposed, but as the lowest conglomerates contain pebbles of gneiss, mica-schist, and hard grit they probably rest upon Archæan rocks.

The lowest fossiliferous band has yielded five species of *Tetragraptus*, associated with *Didymograptus extensus*, *D. nanus*, and small forms of *D. bifidus*. The only other species found at the higher horizon is *Diplograptus dentatus*, and the fauna might be Arenig or Llanvirn. The limestones contain a peculiar trilobite fauna, which leads Mr. Cowper Reed to correlate them with the

Cystidean and *Asaphus* limestones (Llanvirnian) of Sweden and Russia, species common to both being *Nileus armadillo* and *Chasmops cf. Odini*; while others occur in Canada, the genera *Bathyurus* and *Bathyporellus* being essentially American.

The overlying conglomerate has the appearance of lying unconformably on these upper beds, but it is lithologically similar to the Leenane grits, and is probably of the same age.

D. SOME EUROPEAN AREAS

1. France

To British geologists the most important region in France where Ordovician rocks are exposed is that of Brittany, Normandy, and Anjou. In this region they lie in the long synclinal troughs which run roughly from west to east and are most fully developed in the central part of the region, from Grandchamp north of Vannes by Redon and Chateaubriand to Angers in Maine-et-Loire.²⁴ Along this tract the following general succession has been established (see Fig. 44), though some of the subdivisions are not continuous throughout its extent.

		Feet.
Bala	{ Limestone of Rozan with <i>Orthis actonæ</i>	500
	{ Sandstones of Redon and St. Germain (<i>Diplograpti</i>)	
Llandilo	{ The Riadan slates <i>Trinucleus Pongerardi</i>	500
	{ Chatelier sandstone	
Llanvirn	{ The Sion slates with <i>Placoparia</i>	500
	{ The Armorican sandstone	
Arenig	{ Felspathic sandstone and conglomerate	200

The felspathic sandstones (Grès felspathique) are poorly developed in the south of Brittany, but are very thick in the north, from 500 to 1000 feet, and have clearly been formed from the erosion of Archæan and granitic rocks during the interval between the Cambrian and Ordovician sedimentation in this part of France. They may indeed be partly of Tremadoc age (see p. 99).

The Armorican sandstone (Grès armoricain) consists of hard white sandstones with few fossils, chiefly Lamellibranchs of the genera *Redonia*, *Ctenodonta*, and *Actinodonta* and annelid tracks (*Scolithes*, *Bilobites*). It also is much thicker along the northern outcrops than along the southern, where it is sometimes less than 100 feet. Eastward, in Anjou, it is largely represented by shales.

The Sion slates generally have a bed of oolitic ironstone at their base, and the slates contain graptolites of the *geminus* and *Murchisoni* types with the trilobites *Placoparia Zippei*, *Asaphus Guettardi*, and *Calymene Tristani*.

In the south of Brittany the Llandilo Series begins with the sandstone of Chatelier (see Fig. 44), which is overlain near Poligny by the black slates of Riadan, the latter containing *Trinucleus Pongerardi*, *Acidaspis Buchi*, *Illænus Beaumonti*, and *Calymene arago*. In Northern Brittany the series is largely composed of sandstone.

The sandstones of Redon and St. Germain-sur-Ille represent part of the Bala Series, but as they contain few fossils and pass up into Silurian sandstones it is difficult to separate the one from the other, except in the west (Crozon, near Brest), where the two sandstones are separated by a band of limestone yielding *Orthis Actoniæ* and *Illænus Munieri*.

In Normandy the facies is somewhat different and the general succession is as follows :—²⁵

	Feet.
Bala—Green slates with <i>Trinucleus Grenieri</i>	200
Llandilo—Grès de May with <i>Homalonotus</i> , etc. . . .	500
Llanvirn—Blue slates with <i>Calymene Tristani</i>	300
Arenig { Grès armoricain	400
{ Grès felspathique, thinning out S. and E. . . .	variable

It will be seen that in most parts of this area the total thickness is not more than 1500 feet, for the Grès felspathique is only found in the west of the Cotentin and is overlapped to south and west by the Grès armoricain. The overlying *Calymene* slates correspond with those of Sion and Angers and generally have a bed of ironstone at the base.

The Grès de May has recently been subdivided into 4 zones characterised by certain species ; these in descending order are :—

4. Sandstones with *Conularia pyramidata*.
3. Shales and grits with *Trinucleus Bureaui* and *Cal. Tristani*.
2. Sandstone with *Homalonotus* (*Vicaryi* and 3 other sp.).
1. Sandstones with *Dalmanites armoricanus* and *Homalonotus*.

Orthis budleighensis is another common fossil in the lower part of the Grès de May. The highest member of the Ordovician, the shale with *Trinucleus Grenieri*, is not always present ; it is found near Cap la Hague and has a bed of sandstone above it, and thus it is possible that elsewhere it is represented by some of the highest beds of the Grès de May.

In connection with the Ordovician of Normandy brief mention may be made of the area of Ordovician rocks which has long been known to exist in Cornwall. The area occupied by the older Palæozoic rocks in the south-west of Cornwall has recently been resurveyed, but only a small portion of it has been proved to be

Fig. 44.—SECTION ALONG THE VALLEY OF THE VILAINE NEAR POLIGNÉ IN BRITANY (Barrois). Distance about 12 miles.
 S⁴, Silurian.
 S³, Slates of Riadan.
 G, Sandstone of Chatelier.
 S², Slates of Slon.
 S¹, Armorican sandstone.
 S, Cambrian sandstones and slates.
 x, Erivoerian.

Fig. 45.—SECTION THROUGH THE BOHEMIAN BASIN NEAR PRAGUE (after Krejci and Felsmantel). Distance about 10 miles.

G, Devonian.
 F, Devonian-Silurian.
 E, Silurian.
 d₅, } Divisions of
 d₄, } the Ordovician.
 d₃, }
 d₂, }
 d₁, }
 S, } Ordovician
 x, } (Llanvirnian)
 L, } Igneous rocks.

Ordovician by the occurrence of fossils; this is the Gorran quartzite near Mevagissey, in which *Calymene Tristani* has been found and which may therefore represent a part of the Grès de May. Following this quartzite in what is believed to be descending order are the following divisions:—²⁶

Veryan Beds, bluish shales with thin beds of limestone and of chert with Radiolaria.

Portscatho Beds, bluish slates and fine gritty flags.

Falmouth Beds, green and grey slates with layers of sandstone.

Mylor Series, banded slates with alternating layers of fine siliceous grit.

The base is not exposed and no fossils have been found in any of these beds, so that their age is quite uncertain, and their general facies is different from any series in Normandy or Brittany. There is, however, a certain amount of resemblance between them and the Cambro-Ordovician sequence of Belgium (as described below).

2. Spain and Portugal

Rocks of Ordovician age are found in many parts of Spain and Portugal, and the facies which they present in the northern and central parts of these countries is similar to that of Brittany. This facies is well exposed in the cliffs of Asturia on the north coast of Spain. The succession there seen has been described by Professor C. Barrois²⁷ and compared with that of Brittany—

Asturia.	Brittany.
Calcareous shale of el Horno with <i>Endoceras</i> .	} Angers slates. Grès armoricain. Grès felspathique.
Luarca slates with <i>Calymene Tristani</i> .	
White and green grits and dark slates (Cabo Busto).	
Variegated grits with <i>Lingulella Heberti</i> .	

The strata are much flexured and faulted, so that accurate estimates of the thickness could not be made, but Dr. Barrois considered the two lower sets of arenaceous deposits to have a thickness of from 1200 to 1500 feet. The Luarca slates are probably about 300 feet, and the highest beds about 50 feet. The similar succession found at Almaden in Ciudad Real has been described by de Prado (*Bull. Soc. Geol., France, ser. 2, vol. xii. p. 91*), and that of Portugal by Delgado in *Terrenes Palæozoicos do Portugal* (Lisboa, 1876).

3. Belgium

Although the exposures of Ordovician rocks in Belgium are very small, they are interesting because they and another small

tract in Thuringia are the only exposed areas of this system between the extreme west of Europe and Bohemia. In Belgium it is probable that Ordovician rocks form a continuous subterranean outcrop, running for some distance from west to east beneath the Cretaceous deposits south of Ostende and Brussels, but they are only exposed in two or three valleys where the rivers have cut down to them through the superincumbent strata.²⁸

One of these tracts is round the highest tributaries of the river Senne, south of Brussels; another is at the head of the Dyle valley, east of Nivelles; and a third forms a long band north of Namur, from Gembloux on the west to near Huy on the Meuse. The rocks are much compressed, cleaved into slates, and folded into steep-sided anticlines and synclines so that only a general succession has been made out by the discovery of fossils at certain localities. Thus in Brabant the Llanvirn and Arenig faunas have not yet been detected; in Namur a Llanvirn horizon has been found, but the Arenig does not seem to be exposed.

The lowest beds near Huy are black satiny slates yielding *Æglina binodosa* and *Didymograptus Murchisoni*. Near Oxhe to the west are black micaceous grits and slates containing *Homalonotus bisulcatus*, *Trinucleus favus*, and *Orthis redux* (probably Llandilo), while at Fosse a Bala fauna has been found in gritty slates with bands of feldspathic sandstone; the fossils including *Trinucleus seticornis* and *Calymene incerta*. The same fossils with *Orthis Actoniae* have been found near Gembloux.

4. Bohemia

In the Bohemian basin, the position of which is shown on Stanford's map of Central Europe, the Ordovician succession is fairly complete and has a total thickness of about 3000 feet. It is wholly comprised in the Stage D of Barrande, who indicated his systems by letters without giving them special names (see Fig. 45). His sequence is as follows:—

- D 5. Grey and green shales with *Ampyx Portlocki*, *Agnostus tardus*, *Sphaerexochus latens*, and *Dicellograptus anceps*.
- D 4. Sandy micaceous shales, with species of *Trinucleus*, *Æglina*, *Calymene*, and *Cheirurus*.
- D 3. Black shales with *Asaphus nobilis* and *Trinucleus Goldfussi*.
- D 2. Hard grits and shales with *Asaphus ingens*, *Placoparia grandis*, *Acidaspis Buchi*, etc.
- D 1, g. Black shales with *Placoparia Zippei*, *Barrandeia crassa*, *Ogygia desiderata*, *Redonia*, and *Didymograpti*.

Below the last beds and dividing them from the Upper Cambrian

are a series of volcanic rocks—porphyritic lavas with massive beds of ash and agglomerate, which seem to occupy the place of the Arenig Series of Wales.

The groups D 1 and 2 represent the Llanvirn Series, and might be called the *Placoparia* Beds. D 3 occupies the place of the Llandilo Series, though it is only a thin band, and part if not the whole of D 4 is probably of the same age, but D 5 is undoubtedly the equivalent of our Bala Series; its highest portion, however, seems to have been removed by erosion before the deposition of the Silurian.

5. *Scandinavia*

When we pass from Central to Northern Europe we come to a region which was evidently at a considerable distance from the contemporaneous lands and continents, and we find that sedimentation was confined to deposits of limestone and shale. Some geologists have too hastily inferred that these deposits are formed under a great depth of water, but the facts do not warrant such a conclusion, only pointing to the existence of an open sea far away from continental land and favourable for the formation of shelly and crinoidal limestones. It was, however, clearly traversed by currents which carried a certain amount of fine argillaceous sediment, and this in some areas completely prevented the continuous formation of limestones.

In Norway Ordovician rocks are believed to occupy considerable areas, but in most places they are more or less metamorphosed into schists and are plicated with similarly altered Cambrian and Silurian rocks, so that their stratigraphy is difficult to unravel. It is only in the south around Christiania (see the map, Fig. 10) that an undisturbed sequence is found.

In the south of Sweden also there are several tracts (marked on Fig. 10) where a similar succession can be studied; the chief of these are (1) Dalarne, north-west of Stockholm; (2) Nerike, west of Stockholm; (3) in the Gothlands, on each side of Lake Vättern; (4) in Skåne, the most southerly part of Sweden; and (5) in the islands of Öland and Gotland (Visby), in the Baltic.

Within this area also the succession varies, large portions which consist of graptolitic shales in the west and south being replaced by limestones towards the east, and also toward the north in the upper part of the series. The general succession and correlation are as follow :—²⁹

	Argillaceous facies.	Calcareous facies.
Bala.	Brachiopod shales with <i>Staurocephalus</i>	Leptaena limestone of Dalarne.
	Trinucleus shales (<i>T. anceps</i>)	
	Zone of <i>Climacograptus rugosus</i>	Chasmops limestone (<i>C. macrurus</i>).
	„ <i>Dicranograptus Clin-gani</i>	
Llandilo.	„ <i>Climacograptus Scharenbergi</i>	Beyrichia limestone.
	„ <i>Diplograptus mucronatus</i>	
	„ <i>Glossograptus Hincksi</i>	Limestone with <i>Ancistroceras</i> .
Llanvirn.	„	
	„ <i>Didymograptus geminus</i>	Lst. with <i>Ilænus centaurus</i> .
	„ <i>Phyllograptus typus</i>	„ <i>Asaphus</i> and <i>Echino-sphærites</i> .
		„ Sphæronites and trilobites.
Arenig.	„ <i>Isograptus gibberulus</i>	„ <i>Megalaspis limbata</i> and many Cephalopods.
	„ <i>Phyllograptus angustifolius</i>	
	„ <i>Didymograptus balticus</i>	„ <i>Megalaspis planilimbata</i> , <i>Niobe</i> , and <i>Symphysurus</i> .
	„ <i>Tetragrapti</i>	

There are several important points to be noticed in regard to this sequence. The first is that the whole succession, though quite complete and capable of minute subdivision, is only from 300 to 400 feet thick. The second point is that the beds are horizontal and undisturbed. The third is that there is an upward passage from the Cambrian (see p. 102) to the lowest bed which can be classed as Arenig, so that the Swedish geologists prefer to include the Tremadoc in the Ordovician System. Fourthly there is the replacement of shales by limestones.

In the Christiania and Westgothland districts, and in the greater part of Scania, the Arenig and Llanvirn Series are represented by the Lower Graptolite shales about 150 feet thick, but parts of these are replaced by limestone eastward till in Öland the whole consists of limestone. This limestone formation is generally known as the *Orthoceras* limestone from the abundance of *Orthoceratidæ*, and it is only in recent years that its complete equivalence to the graptolitic shales has been established by Moberg, Törnebohm, Hedström, and Winman.

In the same way the graptolitic shales with a *Glenkiln* species are replaced eastward by an *Ancistroceras* limestone and a higher band principally composed of the tests of *Beyrichia* (a small Crustacean), while the *Chasmops* limestone is a still higher horizon occurring in the Christiania district.

In Scania the Bala Series is represented by shales with

Hartfell species of graptolites, but in Dalarne it is replaced by a limestone full of *Leptaena sericea*. The brachiopod shales appear to represent the Upper Bala or Ashgillian division, their lower part in Scania consisting of a greenish argillaceous limestone and the upper of blue flaggy shales.

6. Russia

Ordovician and Silurian rocks occupy a broad area along the south side of the Gulf of Finland, both in the islands of Dago and Oesel, and on the mainland as far east as the southern shore of Lake Ladoga. Part of this area is shown in Fig. 10. The deposits are chiefly limestones with soft marls and shales, quite unaltered but slightly inclined to the south, and their total thickness is about 300 feet.³⁰ The succession is as follows:—

	Feet.
Bala { 8. Borkholm Beds (marls and limestone)	40
7. Lyckholm limestones (corals and trilobites)	50
6. Wesenberg limestone and marls	30
Llandilo { 5. Jewe limestones and shale, <i>Chasmops bucculenta</i>	100
and { 4. Limestones with <i>Chasmops Odini</i>	40
Llanvirn { 3. Echinosphærites limestone	30
Arenig { 2. Vaginatus limestone (<i>Orthoceras vaginatus</i>)	10
1. Glauconitic limestone with <i>Megalaspis</i>	30

Of these beds Nos. 1 and 2 correspond with the lower part of the *Orthoceras* limestone of Sweden, and the next three with its upper part. The age of No. 6 is uncertain, but it contains species of *Chasmops* and *Encrinurus*. The higher beds represent the Trinucleus shales and *Leptaena* limestone. It will be seen that the whole series is essentially calcareous and just as condensed as the Swedish facies, having evidently been formed very slowly in clear water and far from land.

E. CONDITIONS OF FORMATION

From the facts mentioned in the preceding pages it may be inferred that so far as the European region is concerned the geographical conditions of Ordovician time were on the whole similar to those of Cambrian time. Scandinavia and Russia were still farther removed from any large tract of land, and the continued slow subsidence of that area favoured the continual deposition of fine mud or the formation of shelly limestones in water of considerable but not oceanic depth.

The much greater thickness of deposit in Bohemia shows that in passing southwards we approach one of the larger Ordovician

land-areas, and the position of this land seems to be fairly well indicated by the fact that the fauna found in Bohemia differs greatly not only from that of Northern Europe but also from those of the French and British Ordovician. Thus the number of species common to the Ordovician of Britain and Sweden is much larger than the number common to Sweden and Bohemia. It seems clear, therefore, that the Bohemian area belonged to a different life province, and that the land from which the Bohemian sediments were derived lay to the south and south-east of that country, over the region now occupied by Hungary, Roumania, Turkey, the Black Sea, and Asia Minor.

It is probable that nearly the whole of Central and Western Europe was covered by the Ordovician Sea, though there may have been some islands of a fair size. We have indeed evidence of one such island in the centre of the English area, for the absence of Arenig, Llanvirn, and Llandilo rocks to the west of the Longmynd proves that part of Shropshire was land during the greater portion of the period, while the presence of the Caradoc sandstone shows that it was submerged (in part at least) toward the close of Ordovician time.

Of the size and extent of this island we have little to guide us in forming an opinion, but it cannot have reached very far north since Ordovician strata occur at Settle in Yorkshire, and its chief extension was probably eastward. Where the Cambrian is exposed in the Midland counties, as in the Lickey Hills (Worcestershire) and near Nuneaton (Warwickshire), we find it succeeded either by Silurian or Carboniferous rocks, so that probably the whole of the Midland area from Shropshire to Northamptonshire was land during the Ordovician period.

Another island may have existed in the area of the Ardennes where Devonian rocks rest directly on Cambrian.

With regard to the Atlantic region the existence of continental land to the west and north-west of Ireland at this time is proved not only by the enormous thickness of Ordovician deposits in Mayo, but also by the presence of American forms of trilobites in the Arenig limestones of that area (see p. 141). It will be remembered that the Cambrian limestones of Scotland contain a fauna of American affinities, and this fauna is supposed to have migrated along the shores of a North Atlantic land. In Arenig time this land seems to have been greatly enlarged so as to touch the north-west of Ireland, and thus to afford similar facilities for the migration of American species to the Irish area.

How far this Atlantic continent extended over Scotland we do not know at present, but though the old supposition that parts of

the metamorphic complex of the Central Highlands are Ordovician rocks is still held tenaciously by certain authorities the progress of geological research has made this theory more and more improbable. There is therefore good reason to suppose that no such rocks are there, and if this is so the Atlantic land probably extended over the greater part of Scotland, as indeed I have ventured to indicate elsewhere (*Building of the British Isles*).

Lastly there must also have been a land-area of considerable size in a more southern part of the Atlantic to the west of France and Spain, for it is only from that direction that the materials constituting the Ordovician deposits of those countries can have been derived. The felspathic sandstones and conglomerates of Brittany show that part of this land extended very near to France, and also that it consisted very largely of granitic and Archæan rocks.

The greater part of the Ordovician sediments are of the normal detrital character—conglomerates, sandstones, flagstones, grits, mudstones, and shales, the materials of which must have been derived from the land tracts which existed in the positions above indicated.

Limestones were also formed wherever the water was clear enough to permit shell-bearing creatures to live and flourish in great numbers, so that their shells and tests accumulated to form layers on the sea-floor. The chief components of such limestones are Mollusca, Brachiopoda, Crustacea, Bryozoa, and Cystidean Echinoderms. A few genera of corals also contributed to their formation, but do not seem to have been very abundant.

Besides these sediments some of the Arenig shales include layers and nodules of chert which contain remains of Radiolaria, and concerning these some erroneous ideas have arisen as to the conditions indicated by the presence of Radiolaria. This matter has been discussed in the third edition of my *Building of the British Isles* (1911), but it may be well to mention here that those, however, who claim that the radiolarian cherts of this region are "oceanic deposits" jump to a very important conclusion from a very small amount of evidence. Only two reasons have been given for such an inference: (1) the existence of the Radiolaria, which at the present day form deposits on oceanic floors, (2) the small thickness of the Arenig-Llandilo Beds; but neither of these can be taken as evidence of oceanic conditions. As a matter of fact Radiolaria occur in waters of all depths, and have been found in deposits of many ages, notably in the Oxfordian and in the Lower Eocene of Northern France, in each case combined with sponge spicules to form a peculiar siliceous rock termed *gaize*.

Thus the cherts and black shales of the Arenig Series may be compared with the gaize and black clays of the Oxfordian, but have no resemblance to modern oceanic deposits, which are red, yellow, grey, and white, but never black. There are no fine red clays nor foraminiferal limestones among the Scottish Arenig and Llandilo Series, like those which are associated with Tertiary oceanic deposits in Barbados and elsewhere, and the utmost that can safely be inferred from the character and small thickness of the Scottish deposits is that they were formed in clearer water and at a greater distance from land than the Arenigs of Wales.

Finally, it should be noted that in the British area this was a period of great volcanic activity, volcanic vents being opened from time to time on the sea-floor, and probably in most cases they were built up into volcanic islands from which subaerial eruptions took place. This happened in one part of the region or another throughout the whole period. Thus there are volcanic rocks of Arenig age in Pembroke, Merioneth, Scotland, and Ireland (Mayo); of Llanvirn age in Merioneth and Cumberland; of Llandilo age in Merioneth, Carnarvon, and Cumberland; of Bala age in Waterford and Dublin.

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- ¹⁶ C. Lapworth in *Quart. Journ. Geol. Soc.* vol. xxxiv. p. 25, and vol. xxxviii. p. 538; and in *Geol. Mag.* for 1889, pp. 20 and 69.
- ¹⁷ Messrs. Egan and M'Henry, *Sum. Prog. Geol. Survey* for 1899 and 1900.
- ¹⁸ Gardiner and Roberts, *Quart. Journ. Geol. Soc.* vol. liii. p. 520.
- ¹⁹ Reynolds and Gardiner, *Quart. Journ. Geol. Soc.* vol. lii. p. 523.
- ²⁰ *Summary Prog. Geol. Survey* for 1896, p. 48.
- ²¹ Carruthers and Muff, *Irish Naturalist* for 1909, p. 7.

- ²² J. R. Kilroe, *Proc. Roy. Irish Acad.* vol. xxvi. p. 129 (1907).
²³ Gardiner and Reynolds, *Quart. Journ. Geol. Soc.* vol. lxx. p. 104, and vol. lxxi. p. 253.
²⁴ Barrois in *Proc. Geol. Assoc.* vol. xvi. p. 108.
²⁵ A. Bigot, *Bull. Soc. Géol. France*, s. 4, tome iv. p. 861.
²⁶ "Geology of Mevagissey," *Mem. Geol. Surv.* (1907).
²⁷ Barrois, "Terrains anciens des Asturies," *Mem. Soc. Géol. Nord*, 1882.
²⁸ C. Malaise, *Bull. Acad. Roy. de Belg.* for 1910.
²⁹ See W. G. Fearnside in *Geol. Mag.* for 1907, pp. 186 and 257; and the Livret-guides of the International Geol. Congress for 1910.
³⁰ O. Schmidt, *Quart. Journ. Geol. Soc.* vol. xxxviii. p. 514 (1882).

CHAPTER VII

SILURIAN SYSTEM

A. NOMENCLATURE AND DIVISIONS

Nomenclature.—The reasons for restricting the name *Silurian* to the system called Upper Silurian by Murchison have been given on p. 71, but no mention was there made of a subordinate question, namely, the line of separation between the Ordovician and Silurian. Originally the whole of the strata subsequently called Llandovery Beds were included by Murchison in his Upper Caradoc Group, but in 1854 Sedgwick and M'Coy proved that the uppermost sandstones (to which they gave the name of May Hill sandstone) had no connection physically or palæontologically with the Bala rocks, but formed the natural base of Murchison's (Upper) Silurian Series in the typical Silurian areas.

Recognising the justice of this correction, Murchison then separated the beds from the Caradoc sandstone (Bala), and created a new group under the name of "Llandovery rocks," subdividing it into two stages—a lower (linked by some species to the Bala Series) and an upper (closely connected with the Wenlock rocks), but clearly united to one another by a community of *Pentameri* and other fossils. This Llandovery Group he regarded as forming a transition series between his Lower and Upper Silurian.

Some geologists, however, objected to this arrangement on the ground that there is frequently a physical break (overlap leading to unconformity) between the Lower and Upper Llandovery, so that the latter in such localities is dissociated altogether from the former and from the Bala Beds. Consequently, Sedgwick, Jukes, and others drew the line of separation at the base of the Upper Llandovery or May Hill sandstone. But elsewhere there is little or no want of conformity between the members of the Llandovery, and it was pointed out in Chapter II. that small regard must be paid to such local transgressions and unconformities, unless they coincide with a palæontological break.

Recent researches have shown that the Upper Llandovery is usually succeeded by a series of pale grey and green shales (Tarannon shales), and that these three subdivisions (Lower Llandovery, Upper Llandovery, and Tarannon shales) "are far more closely allied to each other than they are to the beds above or below, and that they should be considered as the three consecutive members of a single formation."¹ The Llandoveries were formed in fact during a period of local upheaval and oscillation which intervened between the quiet periods of the Bala and Wenlock Beds. For their equivalents in South Scotland Professor Lapworth has proposed the name *Valentian*, from the Roman name of that province, and this is a convenient designation for the lowermost group or series of the Silurian rocks in Britain.

The second natural division of the Silurian System is typically developed at Wenlock in Shropshire and at Woolhope in Herefordshire. This series was described by Murchison under the name of the "Wenlock formation," and at the localities above-mentioned it consists mainly of shales with a band of limestone at the base and another at the top; but in North Wales and other parts of Britain there are no such limestones, and the only means of delimitation is by the graptolite fauna.

The third division is the "Ludlow formation" of Murchison, which in Shropshire and Herefordshire consists of shales and mudstones with a band of limestone in the middle. Although the shales below the Aymestry limestone were placed in this group by Murchison, he admitted that they were merely a continuation of the Wenlock Series, and for some time it seemed doubtful if they could be separated from it when the Wenlock limestone was absent. Recently, however, it has been shown that they can be distinguished by their graptolites,² and, further, that the Aymestry limestone comes within the highest graptolite zone.

Since, however, these beds are linked to the Wenlock Group by the presence of graptolites and by a common assemblage of trilobites and brachiopoda, Professor Lapworth has proposed to unite them with the Wenlock Beds and to regard them as a primary division under the name of *Salopian*.

The highest beds referable to the Silurian System are a set of shales, flagstones, and sandstones in which no graptolites are found, but which contain remains of a remarkable group of Arachnida—the Eurypterida—and also the bones of certain fish which are the earliest vertebrates found in the British Isles. For these beds the name *Downtonian* has been proposed, but *Clunian* from Clun Forest, proposed by me in 1885 (*Geol. Mag.*), would in some respects be a better name.

This arrangement of the Silurian succession into *Valentian*, *Salopian*, and *Downtonian* has been adopted by many English writers, but it may be doubted whether it is any real improvement on that hitherto employed and still used by the Geological Survey. It is quite as important to recognise that the central mass of beds can be divided into two groups by the different types of graptolites as it is to admit that they are united by a certain community of species. Thus the Wenlock Beds are characterised by species of *Cyrtograptus* and by the *Monograptus priodon* type, and the higher beds by species of the *M. colonus* type. Thus the whole system can be divided into *four* much more equal groups or series on a palæontological basis, and it is probable that this will form the classification of the future. Meantime the several arrangements are shown in the following table :—

Downtonian—Eurypterid Series	{ Downton Beds Upper Ludlow Beds	{ Ludlow Series.
	{ Aymestry limestone Lower Ludlow shale	
Salopian { M. Colonus Series	{ Wenlock limestone	{ Wenlock Series.
{ M. priodon and Cyrtograptus Series	{ Wenlock shales Woolhope limestone	
	{ Tarannon shale	
Valentian—Rastrites and Pentamerus Series	{ Upper Llandovery Lower Llandovery	{ Llandovery Series.

In dealing with the stratigraphy of the system, I shall use the new grouping as affording convenient divisions in the description of the beds, but shall indicate the correlation of the *priodon* and *colonus* series in different areas, so that the student can, if he chooses, adopt the alternative arrangement of Llandovery, Wenlock, and Ludlow Series.

B. LIFE OF THE PERIOD

The following is a brief synopsis of the principal genera which are found in the Silurian System :—

Plantæ.—It is in this system that the earliest remains of plants have been found. Some of these remains are doubtful, but there is general agreement with regard to *Nematophycus* and *Pachytheca*. The former occurs in the form of silicified stems and have been found in Wenlock Beds. *Pachytheca* is a name given to small spherical bodies which may be seeds.

Hydrozoa.—Graptolites are abundant in the lower beds, but gradually decrease in numbers and die out in the upper beds. The family Monograptidæ, including the genera *Monograptus*, *Cyrtograptus*, and *Rastrites*, appears to be confined to the Silurian,

and the only other families represented are the Diplograptidæ and Retiolitidæ. Stromatoporoids become abundant in the Silurian, and are associated with corals as important rock-builders. The principal genera are *Stromatopora*, *Labechia*, and *Clathrodictyon*.

Actinozoa.—Corals are very abundant in the limestones and calcareous beds; most of the Ordovician genera occur, *Favosites*, *Heliolites*, *Halysites*, and *Omphyma* are very common, and the following commence their existence in the British area:—*Acervularia*, *Alveolites*, *Cystiphyllum*, *Arachnophyllum*, and *Stauria*: while the following have only been found in the rocks of this system, *Goniophyllum*, *Rhizophyllum*, *Thecia*, and *Palæocyclus*.

Echinoderma.—Of this phylum the crinoids are by far the most abundant, more than fifty species having been found in British Silurian strata. The following genera are specially characteristic of the Silurian: *Callicrinus*, *Clonocrinus*, *Crotalocrinus*, *Dimerocrinus*, *Herpetocrinus*, *Marsipiocrinus*, *Pisocrinus*, and *Periechocrinus*; and besides these the genera *Cyathocrinus*, *Ichthyocrinus*, *Eucalyptocrinus*, *Hapalocrinus*, and *Taxocrinus* make their first appearance. Cystideans continue to occur, and the genera *Lepadocrinus*, *Placocystis*, *Pseudocrinus*, *Prunocystis*, and *Schizocystis* are specially characteristic of the Silurian period.

Echinoids, which are first found in the Ordovician of Russia, make their appearance in the Silurian of Britain, where they are represented by the genera *Echinocystis*, *Palæodiscus*, and *Palæchinus*.

Crustacea.—Trilobites, though not quite so numerous as in the Ordovician, continue to be common, most of the species belonging to the genera *Calymene*, *Phacops*, *Encrinurus*, *Harpes*, *Acidaspis*, *Illæus*, *Homalonotus*, *Lichas*, *Cheirurus*, *Proetus*, and *Deiphon*, only the last being exclusively Silurian.

Arachnida.—Besides trilobites, another remarkable and extinct order of Arthropods is abundant—the Eurypterida, represented by the genera *Eurypterus*, *Pterygotus*, *Stylonurus*, and *Slimonia*. The Xiphosura, which are allied to the Eurypterida, also occur, but are much less numerous, the principal genera being *Hemiaspis*, and *Neolimulus*.

Brachiopoda are remarkably abundant. Most of the Ordovician genera recur, such as *Lingula*, *Orthis*, *Leptæna*, *Camarotoechia*, and other Rhynchonellidæ, *Strophomena*, *Glassia*, and *Triplecia*; and the following genera make their first appearance: *Atrypa*, *Chonetes*, *Dayia*, *Cyrtia*, *Cyrtina*, *Meristina*, ? *Meristella*, *Pentamerus* (*Conchidium*), *Stricklandia*, *Rhynchotrete*, *Wilsonia*, *Nucleospira*, and *Spirifer*.

Lamellibranchia.—Members of this class also become more

Fig. 46.—GROUP OF LLANDOVERY FOSSILS.

a. <i>Atrypa hemispherica</i> .	d. <i>Stricklandia lens</i> .
b. <i>Meristella angustifrons</i> .	e. <i>Pentamerus oblongus</i> .
c. <i>Orthis reversa</i> .	f. <i>Chiton Griffithi</i> .
g. <i>Cyrtoceras approximatum</i> .	

Fig. 47.—SILURIAN GRAPTOLITES.

a. <i>Monograptus spiralis</i> .	d. <i>Monograptus exiguus</i> .
b. <i>Raistrites peregrinus</i> .	e. <i>Monograptus Sedgwicki</i> .
c. <i>Monograptus gregarius</i> .	f. <i>Monograptus priodon</i> .

abundant in the Silurian period, about 100 species being known in England belonging chiefly to the following genera, *Cardiola*, *Cardiomorpha*, *Ctenodonta*, *Orthonota*, *Cleidophorus*, *Grammysia*, *Amboychia*, *Pterinea*, *Conocardium*, *Lunulicardium*, and *Modiolopsis*.

Gastropoda are fairly numerous, about sixty species being known from the English Silurian. Most of them are referable to the following genera: *Pleurotomaria*, *Murchisonia*, *Bellerophon*, *Platyschisma*, *Omphalotrochus* (*Horiostoma*), *Cyclonema*, *Eunema*, *Holopea*, *Holopella*, *Platyceras* (= *Acroculia*), and *Subulites*. The last genus is noteworthy as possessing a channelled mouth, and *Murchisonia* has a very short anterior canal, all the rest being holostomous.

Cephalopoda.—These are also numerous; but all the genera belong to the Nautiloidea; they include species of *Orthoceras*, *Phragmoceras*, *Gomphoceras*, *Trochoceras*, *Tretoceras*, *Ophidioceras*, *Cyrtoceras*, *Actinoceras*, and *Ascoceras*, the last being only known as a Silurian form.

Fishes.—The earliest remains of vertebrate animals hitherto found in Britain occur in the Ludlow Series, and are the remains of fish belonging to the sub-class or order *Ostracodermi*. The chief genera are *Pteraspis*, *Cephalaspis*, *Auchenaspis*, *Scaphaspis*, and *Eukeraspis*. The sub-class *Elasmobranchii* is represented by *Onchus* (spines) and shagreen-like plates referred to *Cœlolepis* and *Thelodus*.

The greater part of the Silurian System is capable of subdivision into zones by means of the graptolite faunas, and though these are not equally developed in all localities they always occur in the same order of succession. No species have yet been recognised in the Upper Ludlow Beds, but from the Aymestry limestone downward the following zones have been recognised:—

	Zone of <i>Monograptus</i> <i>Leintwardinensis</i> .	
Lower Ludlow	{	” ” <i>tumescens</i> .
		” ” <i>scanicus</i> .
		” ” <i>Nilssoni</i> .
		” ” <i>vulgaris</i> .
Wenlock Beds	{	” <i>Cyrtograptus</i> <i>Lundgreni</i> .
		” ” <i>rigidus</i> .
		” ” <i>Linnarssoni</i> .
		” ” <i>symmetricus</i> .
		” <i>Monograptus</i> <i>Riccartonensis</i> .
		” <i>Cyrtograptus</i> <i>Murchisoni</i> .
Valentian (Llandovery)	{	” ” <i>Grayæ</i> .
		” <i>Monograptus</i> <i>crispus</i> and <i>M. exiguus</i> .
		” <i>Rastrites</i> <i>maximus</i> .
		” <i>Monograptus</i> <i>spinigerus</i> and <i>Cryptograptus</i> <i>conieta</i> .
		” ” <i>gregarius</i> .
	{	” <i>Diplograptus</i> <i>acuminatus</i> and <i>vesiculosus</i> .

Fig. 48.—GROUP OF WENLOCK FOSSILS.

a. <i>Acervularia luxurians</i> .	e. <i>Strophonella euglypha</i> .
b. <i>Omphyma subtrubatum</i> .	f. <i>Spirifer plicatellus</i> .
c. <i>Atrypa reticularis</i> .	g. <i>Horlostoma discors</i> .
d. <i>Leptaena rhomboidalis</i> .	h. <i>Cyathophyllum truncatum</i> .
i. <i>Arachnophyllum Murchisoni</i> .	

The following are some of the other fossils which are specially characteristic of each of the three Silurian series or divisions :—

Fossils of the Llandovery and Valentian Series

Hydrozoa.

(See table of graptolite zones.)

Actinozoa.

Lindstroemia bina, Lind. *subduplicata*, *Pinacopora Grayi*.

*Echinoderma.**Crustacea.**Brachiopoda.*

Palæchinus Phillipsi (but none are common).

Illænus æmulus, Phacops Weaveri, Ph. elegans.

Lingula crumena, Atrypa hemispherica, Meristella crassa, M. angustifrons, Stricklandia lens, Pentamerus oblongus, P. undatus, Orthis reversa.

Lamellibranchia. Ctenodonta Eastnori, Orthonota amygdalina, and O. inornata (both range into Wenlock).

Fig. 49.—GROUP OF WENLOCK FOSSILS.

a. Lepadoerinus quadrifasciatus.

b. Periechoerinus moniliformis.

c. Calymene Blumenbachi.

d. Phacops caudatus.

e. Bellerophon dilatatus.

f. Orthoceras annulatum.

Gastropoda.

Turbo tritorquatus, Holopella cancellata, Omphalotrochus prenuntius.

Cephalopoda.

Tretoceras bisiphonatum, Cyrtoceras approximatum, Orthoceras conicum.

*Fossils of the Wenlock Series**Hydrozoa.*

(See table of graptolite zones.)

Actinozoa.

Acervularia luxurians, Arachnophyllum Murchisoni, A. typus, Strombodes diffluens, Cyathophyllum truncatum, Omphyma turbinatum, Heliolites interstinctus (from Bala), Favosites gottlandicus.

Fig. 50.—GROUP OF LUDLOW FOSSILS.

- a. *Orthoceras tenuicinctum*.
- b. *Orthis lunata*.
- c. *Pentamerus Knighti*.
- d. *Rhynchonella nucula*.

- e. *Pterinea retroflexa*.
- f. *Avicula Danbyi*.
- g. *Dayia navicula*.
- h. *Homalonotus delphinocephalus*.

- Echinoderma.* Actinocrinus (Glyptocrinus ?) pulcher (from Llandov.), Periechocrinus moniliformis, Crotalocrinus rugosus, Marsipiocrinus cælatus, Lepadoocrinus quadrifasciatus.
- Crustacea.* Illænus barriensis, Phacops caudatus (Val. to Lud.), P. Downingiæ, Calymene Blumenbachii (Bala to Lud.), Encrinurus punctatus, Lichas anglicus (to Lud.).
- Brachiopoda.* Atrypa reticularis, Pentamerus galeatus, Strophonella euglypha, Leptæna rhomboidalis (Llan. to Lud.), Orthis rustica, O. elegantula (Bala to Lud.), Spirifer plicatellus, Retzia? Barrandi, Wilsonia Wilsoni, Camarotoëchia borealis, Cyrtia exporrecta.
- Lamellibranchia.* Cardiola interrupta, Grammysia cingulata.
- Gastropoda.* Horiostruma discors, H. rugosus, Eunema cirrhosis, Platyceras (Acroculia) haliotis, Bellerophon dilatatus.
- Cephalopoda.* Orthoceras annulatum, Phragmoceras ventricosum, Gomphoceras pyriforme, Trochoceras asperum, Barandeoceras bohemicum.

Fossils of the Ludlow Series

- Porifera.* Ischadites Kœnigi, Favospongia Ruthveni.
- Echinoderma.* Ichthyocrinus pyriformis (from Wenlock), Lapworthura Miltoni, Palæaster Ruthveni, Palæocoma Colvini, Palæodiscus ferox, Echinocystis pomum.
- Crustacea.* Homalonotus delphinocephalus (from Wenl.), H. Knighti, Acidaspis coronata, A. Hughesi.
- Arachnida.* Pterygotus arcuatus, Eurypterus abbreviatus, Hemiaspis limuloides.
- Brachiopoda.* Pentamerus Knighti, Dayia navicula, Camarotoëchia nucula (from Val.), Orthis lunata, Chonetes striatella (and var. lata), Orbiculoidea rugata, Lingula cornea, L. Lewisi (from Wenl.).
- Lamellibranchia.* Avicula Danbyi (from Val.), Pterinea retroflexa, Cardiola striata, and C. interrupta (both from Wenl.), Orthonota semisulcata.
- Gastropoda.* Cyclonema coralli, Murchisonia coralli, Holopella gregaria, Platyschisma helicites.
- Cephalopoda.* Orthoceras bullatum, O. tenuicinctum, O. ludense, Trochoceras giganteum, Ascoceras Barrandi.
- Pisces.* Scaphaspis ludensis, Cephalaspis ornatus, Auchenaspis Salteri, Thelodus parvidens.

C. BRITISH SILURIAN ROCKS

Range and Relation to Older Rocks.—Silurian rocks occupy surface-tracts in the following districts. They form a continuous outcrop of varying width through Wales from Carmarthenshire in the south to the Denbigh coast on the north. They spread westward through Radnorshire and parts of Shropshire, and they reappear from beneath newer rocks as inliers in Stafford-

shire, Hereford, and Monmouth. In all probability they have a considerable subterranean extension under Central and Southern England, for they appear as far south as Cardiff and the Mendip Hills, and have been reached in borings at Ware in Hertfordshire and at Rochester in Kent.

In North Lancashire and Westmoreland they again rise to the surface in a considerable tract south of that occupied by the Ordovician, extending from the Duddon estuary on the west to Sedburgh and Rathay Bridge on the east, a distance of about 35 miles with an average width of 14 miles.

In the south of Scotland they cover a much larger area, ranging completely across the Southern Uplands from the Mull of Galloway to the coast of Berwick. There is also an outlying tract in Lanark, and it is probable that they underlie parts of the Central Lowlands, for the same Lanarkian Beds have recently been recognised on the coast of Kincardine.

In Ireland there are many isolated exposures in the south and west and a large area in the north-east, occupying parts of Down, Armagh, Monaghan, Cavan, and Louth.

In most parts of the British Isles there is no great break or unconformity between the Silurian and Ordovician, but it so happens that in the typical districts of Shropshire and Radnorshire a strong local discordance and unconformity is found, due evidently to local uplifts which produced more than one break in the sequence. In other areas the sea-floor may have been raised and the depth of water lessened without any part of it being lifted above the surface of the sea and brought into the sphere of erosive agencies. Under such circumstances uplift is indicated only by changes in the character of the sediment and in the component members of the marine fauna.

1. *The Typical Silurian Area*

We shall consider this as including all the more eastern exposures, and especially those which occur between the Welsh borders and the valley of the Severn. It will embrace not only the Wenlock and Ludlow districts of Shropshire, but that of Presteign in Radnor, as well as those of Malvern, Woolhope, and May Hill in Hereford, Usk in Monmouth, and the outcrops in Staffordshire. These were the places where the beds were first studied by Murchison, and where they present a more calcareous and more richly fossiliferous facies than in any other part of Britain.

Llandovery Beds.—In this region the Lower Llandovery is absent, and the Tarannon shales are very thin, so that the

total thickness of the Valentian Series is much less than it is in Wales.

In the southern districts (Usk, May Hill, Woolhope, and Malvern) the group consists of the May Hill sandstone and the Woolhope shales. The former is about 1000 feet thick, and consists of (1) a lower set of sandstones and conglomerates of grey and purple colours about 600 feet thick, and yielding the usual fossils, together with *Otenodonta Eastnori* and *Lingula crumena*; (2) an upper set of grey laminated sandstones and shales from 320 to 500 feet thick with *Pentamerus lens*, *P. undatus*, etc., the highest beds being shales which are doubtless equivalent to the

Fig. 51.—SECTION THROUGH HIGH WOOD NEAR WEST MALVERN (Professor Groom).
(Scale 6 inches to 1 mile.)

Tr. Trias.	MS ₂ . Upper	} May Hill sandstone.
WS. Wenlock shale.	MS ₁ . Lower	
WL. Woolhope limestone.	BS. Black shales (Cambrian).	
WS. Woolhope shale.	Arch. Pre-Cambrian.	
	FF. Faults.	

Tarannon shales. The conglomerates rest unconformably upon the Cambrian shales where these are exposed, but elsewhere they are faulted against the Archæan rocks. The Woolhope shales are not more than 200 feet thick, consisting of green and purple shales with thin layers of limestone.

In Shropshire the group consists of the following members:—

Purple shales (=Tarannon shale)	200 to 400 feet.
Pentamerus limestone	30 to 40 „
Basement grits and conglomerates.	0 to 120 „

The basement beds rest unconformably on Ordovician, Cambrian, and Longmyndian in different parts of the area, varying greatly in thickness, and in places thinning out altogether so as to leave the overlying limestone in contact with the older rocks. Thus the *Pentamerus* limestone is really a sandstone rendered calcareous by the quantity of included fossil shells. The commonest fossils are

Pentamerus oblongus, *P. undatus*, *Stricklandia lens*, *Atrypa hemispherica*, *Strophomena pecten*, *Encrinurus punctatus*. The overlying shales consist in the Wenlock district of purple, red, and green shales with few fossils, and are distinguishable by their colours from the overlying Wenlock shales.

Salopian Series.—The succession of limestones and shales which form this series at Woolhope and Malvern is shown in Figs. 51 and 52. The Woolhope limestone is from 50 to 250 feet thick, the Wenlock from 250 to 400, and the Aymestry about 250 feet, while the intervening shales vary from 500 to 900 in different places, and the average total thickness of the series is over 2000 feet.

The Woolhope limestone is also present near Presteign in Radnor, but thins out northward and is only represented in Shropshire by a band of calcareous and fossiliferous shale. The whole series forms a broad band from the southern border of this county to the river Severn at Coalbrookdale, the Wenlock and Aymestry limestones forming well-marked escarpment ridges, rising above the outcrops of the shale as the beds are here dipping steadily to the east (see map, Fig. 21). The succession found near Wenlock was well described by Mr. W. Maw in 1881,³ from whose paper Fig. 53 has been copied.

The Buildwas Beds, which here represent the Woolhope limestone, are exposed in a small cliff opposite Buildwas Abbey, and are shales which yield an immense number of small brachiopoda, *Orthis biloba*, *O. elegantula*, *O. Lewisi*, *O. hybrida*, *Leptana segmentum*, *Nucleospira pisum*, and *Atrypa* (? *Retzia*) *Barrandi*. Mr. Maw considered these beds to represent the Woolhope limestone of more southern localities. The Tickwood Beds are shales with layers of nodular limestone, the shales predominating in the lower part and the limestones in the higher part below the massive limestone of Wenlock edge, so that it is not easy to say where the one ends and the other begins. Fossils are abundant in these beds.

The Wenlock limestone is well exposed at Benthall Edge and in quarries near Wenlock; it is a grey earthy limestone, generally lying in thin beds with shaly partings, and is highly fossiliferous. Some of the beds appear to be largely made up of corals which weather out finely in the spoil-heaps, while others contain quantities of Brachiopoda and Mollusca.

The Lower Ludlow shales consist of soft grey sandy shales, often showing a tendency to spheroidal structure, and their total thickness is about 900 feet in the Wenlock and Ludlow district. In the Wenlock area they do not contain graptolites, but have yielded many other fossils, of which the following are some of the

commonest : *Lingula lata*, *Wilsonia Wiltoni*, *Camarotoechia nucula*, *Leptæna levigata*, *Chonetes striatella*. At the top of these shales there are some beds of earthy flagstone which are quarried and are known as the Leintwardine flags ; they contain remains of starfish (*Lapworthura* and *Palæocoma*), large *Orthoceras*, and Arthropods of the genera *Pterygotus* and *Eurypterus*.

The Aymestry limestone is a bluish-grey earthy limestone of varying thickness, and often split into several beds by intercalated bands of shale. At Aymestry it is well exposed in the gorge of the river Lugg and is said to be 175 feet thick. Its commonest fossils are *Pentamerus Knighti*, *Lingula Lewisi*, *Wilsonia Wiltoni*, and *Dayia navicula*. The outcrops of the Ludlow Beds in the typical district of Ludlow and Aymestry are shown in Fig. 56. The total thickness of the series in Shropshire is about 2600 feet.

In Staffordshire the Woolhope limestone reappears at Great Barr, east of Walsall, the Wenlock Beds are well exposed at Dudley and the higher beds at Sedgeley, the Silurian at all these places being brought up in anticlinal flexures from which the overlying Carboniferous rocks have been removed by denudation.

Downtonian.—In Shropshire the Upper Ludlow shales consist in the lower part of soft grey shales with thin bands of limestone, and in the upper part of grey and green calcareous flags at the top of which is a bed of greenish-grey argillaceous sandstone surmounted by greenish laminated sandstones, including a thin layer consisting of the bones and spines of fish and large Crustacea ; this layer is known as the "bone bed," and has been met with at many localities.

The bone bed is succeeded by the Downton sandstone, a fine-grained and thin-bedded yellowish sandstone which is quarried for building stone at Downton Castle near Ludlow, and contains *Lingula cornea*, *Pteraspis Banksi*, *Eurypterus lineatus*, and other Merostomata. This is about 50 feet thick, and is succeeded by reddish flagstones and olive-green shales which yield *Lingula cornea* with remains of fish and Crustacea. Above these are purple sandstones without fossils.

In a recent paper the Misses Elles and Slater⁴ recognise the following subdivisions, with a total thickness of 540 feet :—

	Feet.
Eurypterus shales . . .	120
Downton sandstone . . .	50
Chonetes flags . . .	150
Rhynchonella flags . . .	120
Dayia shales . . .	100

A similar series reappears in the Woolhope and Malvern districts

and are well exposed in the cutting near Ledbury station, west of Malvern, where the sequence is as follows :—

	Feet.
Old Red marls and sandstones	—
Downtonian { Ledbury shales	400
{ Downton sandstone	90
{ Upper Ludlow shales	140
Aymestry limestone (seen in the tunnel)	—

From the Ledbury shales *Lingula cornea* with remains of *Cephalaspis* and *Pterygotus* have been obtained.

The most southerly occurrences of Silurian rocks of Salopian type are at Fortworth, in Gloucestershire, and in the Mendip Hills, where a small inlier has recently been discovered and described. It is noteworthy that where the base of the Devonian comes to the surface in Cornwall it does not rest on Silurian but on Ordovician and older rocks, having probably overlapped the Silurian.

2. Wales

The Valentian attains its greatest thickness in Central Wales where it occupies large parts of Cardigan and Radnor, and has a maximum thickness of 5000 feet. The most complete development of the Llandovery Beds is found within the western part of the area near Rhyader in Radnor, and has recently been worked out by Mr. H. Lapworth, from whose account the following is taken.⁵ He describes the Lower Llandovery under the name of the Gwastaden Group, the Upper Llandovery as the Caban Group, and the Tarannon shale as the Rhyader pale slates. The Gwastaden Beds seem to succeed the Bala Beds without any break, but there is a strong unconformity between the Gwastaden and Caban Groups, and the latter is overlapped by the Rhyader slates, so that the structure of the district is somewhat complicated. Fig. 54 is a diagrammatic view constructed by Mr. Lapworth of the succession and of the relations of the rock-groups when faults and folds are eliminated.

He estimates the thickness of the Gwastaden Series at over 1000 feet, that of the Caban Group as 1500 (maximum); that of the Rhyader (Tarannon) slates is not given, but they extend over a large area of ground between Rhyader and Llanidloes, where they are probably 1500 feet thick, so that in this district the Llandovery or Valentian Series has a total thickness of nearly 5000 feet.

When traced eastward or south-eastward the Gwastaden Beds are found to thin out entirely and the thickness of the Caban Beds and Tarannon shales is greatly reduced. North-east of Builth they form quite a narrow band and rest unconformably on Llandilo

Fig. 54.—DIAGRAMMATIC SECTION TO SHOW THE RELATION OF THE LLANDOVERY BEDS NEAR RHYADER (by H. Lapworth).

The Rhyader slates are plotted as if horizontal. Distance about 7 miles. A. Members of the Gwastaden Group. B. Members of the Calan Group.
C. Rhyader slates (Tarannon).

Fig. 55.—SECTION FROM WERN FAWR TO TRECOED NEAR BWLTH (Miss Elles).

- d. Llandovery Beds.
- c. Wenlock slates.
- b. Llandovery Beds.
- a. Llandovery Beds.
- 1. Flagstones.
- 2. Zone of *Cyrt. rigidus*.
- 3. Zone of *Cyrt. Lundgreni*.
- 4. Flagstones.
- 1. Zone of *Cyrt. Murchisoni*.
- 2. Zone of *Mon. rhyacionensis*.
- 3. Zone of *Cyrt. symmetricus*.
- 4. Zone of *Cyrt. Llandoveryensis*.

slates. Southward they extend into Carmarthenshire, both Upper and Lower divisions being well developed at Llandovery, but south of that place they are cut out by faults.

Northward the Rhyader facies is continued through Montgomery, but the several members of the series become much thinner till, near Bala and Corwen on the Dee, the whole is reduced to less than 1000 feet. At Corwen it consists of the following beds:—

Tarannon shales	300 feet.
Graptolitic mudstones	300 „
Corwen grits	200 „

The position of these beds is shown in Fig. 57. The Corwen grits are grey and white sandstones with bands of coarse and pebbly sandstone, and are believed to vary from 50 to 300 feet in thickness. They contain few fossils, but *Meristella crassa* and *Pentamerus oblongus* have been found, which are Lower Llandovery species. Above them are soft bluish-grey or black mudstones which contain *Monograptus gregarius*, *M. tenuis*, and *Climacograptus normalis*; and these pass up into the pale Tarannon slates.

In North Denbigh the whole series is less than 500 feet thick, but the zonal succession of beds has been more fully made out by the Misses Elles and Wood,⁶ these being:—

	Beds.	Zones.
Gyffin Shales, 300 feet.	Light-coloured shales with black bands.	Monograptus crenulatus.
		Monograptus crispus.
	Grey shales, flags, and mudstones.	Rastrites maximus.
		Monograptus Sedgwicki.
		Monograptus gregarius.
		Mesograptus modestus.
	Conway Castle grits and Bryn Dowski flags, 150 feet.	

The lowest beds contain *Diplograptus tamariscus*, *Climacograptus normalis*, and other species of Lower Llandovery graptolites.

Salopian.—When the Wenlock Beds are traced westward from Presteign through Radnorshire both the limestones are found to thin out, leaving a continuous series of mudstones and shales. The Lower Ludlow shales also persist, but the Aymestry limestone at their summit disappears.

The subdivision of this mudstone series was practically impossible so long as lithological differences only were relied upon as a means of classification, but in 1880 Professor Lapworth drew attention to the graptolite fauna of these beds, and expressed the belief that “by the aid of the lowly graptolite the geologist of the future will be able to read off the natural succession” of the monotonous Silurian mudstones. This has been accomplished

in Radnorshire and West Shropshire by Miss G. L. Elles⁷ and Miss E. M. R. Wood,⁸ the former dealing with the Wenlock succession and the latter with the Lower Ludlow.

The country round Builth may be taken as the type of this graptolitic facies of the Wenlock Series, and Miss Elles has shown

Fig. 56.—MAP OF THE LUDLOW DISTRICT.

that it contains a fauna of twenty-three species and varieties of graptolites, by means of which it can be divided into six zones. The succession of the beds is shown in Fig. 55, which is taken by permission from her paper. The total thickness appears to be about 2500 feet, but there are two partial breaks in the series, for the flagstones of zone 4 overlap the beds below, so that in one place they rest on the lower part of zone 2, and again, there is

reason to think that the upper beds of zone 5 are sometimes concealed by an overlap of zone 6 (*Cyrtograptus Lundgreni*), which represents the Wenlock limestone.

The shales overlying this zone are similarly divisible, and Miss Wood has distinguished five zones in the following descending order:—

		Feet.
5.	Zone of <i>Monograptus Leintwardinensis</i> , including the Aymestry limestone	400 to 500
4.	„ <i>Monograptus tumescens</i>	100 to 220
3.	„ <i>Monograptus scanicus</i>	250 to 100
2.	„ <i>Monograptus Nilssoni</i>	} 300 to 400
1.	„ <i>Monograptus vulgaris</i>	

Thus the total thickness of the Salopian Series in the Builth district is about 2600 feet.

When these beds are followed northward they become more arenaceous, thick felspathic grits and micaceous flags appearing in the Wenlock shales, while the higher beds are gradually replaced by a great mass of sandstones, grits, and flagstones in which fossils are much less abundant. This is the aspect presented by the Salopian Series in Denbighshire, where parts of them have been studied by Mr. Philip Lake,⁹ Professor T. M^cK. Hughes,¹⁰ Dr. H. Hicks,¹¹ and by the Misses Elles and Wood¹² (see Figs. 57 and 58). Combining the observations and correlations of these authors, we find that the succession may be generalised as follows:—

	6. Gritty sandstones and wavy banded concretionary mudstones of Moel Ganol.
Salopian.	{ 5. Grey banded mudstones and sandstones with <i>Acidaspis Hughesi</i> .
	{ 4. Nantglyn flags with <i>Actinocrinus pulcher</i> , <i>Camarotoechia nucula</i> , <i>Dayia navicula</i> , <i>Orthoceras Sedgwicki</i> , <i>O. primærum</i> , <i>Cardiola interrupta</i> , and <i>Monograptus Nilssoni</i> .
	{ 3. Moel Ferna slates with <i>Monograptus priodon</i> and <i>M. Flemingi</i> .
	{ 2. Pen-y-glog grit with <i>Meristella tumida</i> , <i>Strophomena depressa</i> , <i>Phacops sp.</i> , and <i>Enerinites</i> .
	{ 1. Pen-y-glog slates with <i>Cyrtograptus Murchisoni</i> , <i>Gladiograptus geinitzianus</i> , <i>Monograptus priodon</i> , and <i>M. vomerinus</i> .

The slates at the base are the equivalents of the lower part of the Wenlock shales, and the same fossils have been found in beds overlying the Tarannon shales near Conway. The Moel Ferna Beds must include the representative of the Wenlock limestone, but they yield very few fossils. The Nantglyn flags represent the Lower Ludlow Beds, and Miss Elles has recognised two zones in them, a lower zone of *Monograptus vulgaris* and a higher one of *M. Nilssoni*. In the valley of the Dee Mr. Lake found some micaceous flagstones which contain *Monograptus Leintwardinensis* in abundance,

and these cannot be far below the horizon of the Aymestry limestone. This zone is probably to be found in the banded beds (No. 5) of the Clywd valley section, but has not yet been detected there. In South Denbigh the highest beds occur at Dinas Bran near Llangollen, and have yielded *Orthoceras Sedgwicki*, *Cucullela coarctata*, *Dayia navicula*, *Chonetes minima*, and other fossils.

The series is believed to be over 5000 feet thick, and is nevertheless incomplete owing to the unconformable superposition of the Carboniferous rocks.

Downtonian.—In the country round Kington, Clun, and Radnor Forest these graptolitic shales are succeeded by a great thickness of brownish sandy shale with beds of brown flagstone and sandstone, which are shown in the sections of the Geological Survey to be from 1700 to 2000 feet thick.

The highest beds in Denbighshire, *i.e.* the sandstones and mudstones of Moel Ganol, may represent the Upper Ludlow shales, but proof of such equivalence has not yet been found. That beds of Ludlow age did originally extend over Denbigh is proved by the occurrence of fossiliferous pebbles in the conglomerate at the base of the Carboniferous Series near Abergele.¹³ These are pebbles of green and red sandstone containing *Orthis lunata*, *O. filosa*, *Chonetes striatella*, *Spirifer elevatus*, *Pterinea retroflexa*, and a few other species.

3. Westmoreland

The Silurian sequence in the north of England does not differ greatly from that of North Wales, but it is much more complete, has been more fully investigated, and the beds are also rather more fossiliferous, so that they are more easily subdivided. For a long time the correlation of the Westmoreland Groups with those of Shropshire and Radnor was very uncertain, but the recent studies of graptolites by Messrs. Marr and Nicholson,¹⁴ by Miss G. Elles,¹⁵ and by Misses Watney and Welch¹⁶ have placed the comparison on a sounder basis.

Valentian.—Where the sections are most complete, as in Stockdale and at Spengill, there are no arenaceous beds of the Llandovery type, but a series of shaly mudstones resting directly on the Ashgill shales with apparent conformity (see Fig. 37). In some parts of the area, however, the lowest shales are replaced by a few feet of gritty conglomerate. The ordinary facies is known as the Stockdale Shales; their total thickness is not more than 250 feet, but divisible into two sub-groups: (1) the Skelgill Beds, (2) the Browgill Beds. By the Geological Survey

the groups are called (1) the graptolitic mudstones and (2) the Pale slates.

The Skelgill Beds have a thickness of 70 or 75 feet, and have at the base a thin limestone containing *Atrypa flexuosa*, succeeded by shale with *Dimorphograptus confertus*. The middle beds contain *Monograptus gregarius* and *Rastrites peregrinus*, with *Encrinurus punctatus* and *Phacops glaber*. The higher beds yield *Monograptus spinigerus* and *M. Clingani*, with many trilobites, and in the Spengill section there is a still higher band containing *Rastrites maximus* in abundance.

The Browgill Beds are thicker (about 140 feet) but less fossiliferous. They are divisible into three parts: (1) a zone of *Monograptus turriculatus*; (2) a zone of *Monograptus crispus*; (3) barren shales and grits.

Salopian.—This series attains a very great development in Westmoreland and consists almost entirely of flagstones, sandstones, and grits, with only subordinate bands of shale. The equivalents of the Wenlock Beds are really of less thickness than they are in Shropshire, but those above the horizon of the Wenlock limestone (zone of *Cyrt. Lundgreni*) are very much thicker. The following is a tabular view of the lithological divisions and the graptolitic zones:—

Divisions.	Zones.
<i>Bannisdale slates</i> (4000 feet). Sandy mudstones with beds of hard sandstone. <i>Orthoceras primævus</i> and <i>O. subundulatum</i> .	} <i>M. Leintwardinensis</i> .
<i>Coniston grits</i> (4000 feet). Red grits and flags with <i>Cardiola interrupta</i> , <i>Pterincatenuistriata</i> , <i>Dayia navicula</i> , and <i>Orthis lunata</i> .	
<i>Coldwell flags</i> (2000 feet). Grey flags and grits with <i>Acidaspis Hughesi</i> , <i>Actinocrinus pulcher</i> , <i>Monograptus colonus</i> , and <i>M. Ræmeri</i> .	} <i>M. tumescens</i> . <i>M. scanicus</i> .
<i>Coldwell grits</i> (800 feet). Coarse grey grits.	
<i>Brathay flags</i> (1000 feet). Fine-grained bluish laminated flagstones, comparable with the Wenlock shales and divisible into 3 zones.	} <i>M. vulgaris</i> (probably). <i>C. Lundgreni</i> . <i>C. rigidus</i> . <i>M. Riccartonensis</i> . <i>C. Murchisoni</i> .

Downtonian.—This group seems to be represented by certain beds which succeed the Bannisdale slates and consist in the lower part of bluish thin-bedded sandstones with subordinate beds of shale, containing *Protaster Miltoni*, *Dayia navicula*, *Cucullella Cawdori*, *Phacops Downingia*, and other fossils. There is also a calcareous band which contains *Palæaster*, *Proëtus latifrons*, and *Dayia navicula*, and has been identified by Mr. Aveline with the Aymestry limestone. These beds are about 1200 feet thick.

The highest beds, or *The Kirkby Moor flags*, are massive greenish and grey sandstones, with calcareous (fossiliferous) bands, passing

up into thin-bedded flags. This group is more than 2000 feet in thickness. Fossils are abundant, the following being some of the most characteristic:—*Lingula cornea*, *Discina rugata*, *Spirifera elevata*, *Grammysia cingulata*, *Orthoceras ludense*, and *Trochoceras ibex*.

4. South of Scotland

The Silurian succession in this region was first deciphered by Professor Lapworth,¹⁷ who described the two special facies exhibited by the rocks of Valentian age near Moffat in Dumfries, and near Girvan in Ayrshire. More recently the whole region of the southern uplands has been described in detail by Messrs. Peach and Horne.¹⁸ The Silurian rocks occupy the southern half of the upland region in a broad belt from 20 to 30 miles in width, extending from the Berwick coast on the east to that of Wigtown on the west. On the northern side they occur as isolated exposure in Ayrshire, in Lanark, and in the Pentland Hills.

Valentian.—In Dumfries and the central belt the lowest beds are soft black shales, known as the Birkhill shales; they lie conformably upon the Hartfell shales (Bala), are equivalent to the Skelgill shales of Westmoreland, and are of about the same thickness (140 feet) (see Figs. 40 and 41, p. 133). They are rich in graptolites, and are divisible into the following zones:—

Upper Birkhill	{	Zone of <i>Rastrites maximus</i> .
		„ <i>Monograptus spinigerus</i> .
		„ <i>Petalograptus cometa</i> .
Lower Birkhill	{	„ <i>Monograptus gregarius</i> .
		„ <i>Diplograptus venuculosus</i> .
		„ <i>Diplograptus acuminatus</i> .

These shales are succeeded by a thick series of sediments, from 3000 to 4000 feet, which are the equivalents of the Browgill Beds and the Tarannon shales. They are called the Gala Group by Professor Lapworth, and have been divided by the Survey into three stages, but fossils are rare except in the lowest or Abbotsford flags, which contain *Monograptus turriculatus*, *M. crispus*, *M. exiguus*, etc.

In the Girvan area the Birkhill shale is represented by a much thicker series of a Llandovery type, and about 1000 feet thick. The lower beds contain Lower Llandovery fossils, while the succeeding beds include a limestone with many Upper Llandovery fossils, such as *Pentamerus oblongus*, *Stricklandia lens*, *Illænus æmulus*, and *Phacops Stokesi*. Above this, and representing the Gala Group, are the Penkill Beds (also 1000 feet thick), the topmost of these being mudstones containing *Cyrtograptus Grayæ*.

Salopian.—In the main belt the Gala Group is succeeded by the Riccarton Beds, a series of conglomerates, grits, mudstones, and shales from 1000 to 1500 feet thick, and containing *Cyrtograptus Murchisoni*, *Monograptus vomerinus*, and *M. priodon*. At Raeberry near Kirkcudbright there are still higher beds, consisting of green marls with limestone nodules, which are either highest Wenlock or possibly Lower Ludlow. These are 700 feet thick.

In the Girvan area the representatives of the Wenlock Beds consist largely of unfossiliferous flagstones, and only the lower part of the series is exposed. This is divided into two groups by Professor Lapworth. The lower or Bargany Group has a thickness of about 700 feet, the only fossils being the graptolites *Monograptus acus* and *M. priodon*. The higher group he called the Straiton Beds, at the base of which are olive-green flags well seen at Drumyork, succeeded by shales containing *Monograptus vomerinus*, *Cardiola fibrosa*, *Orthonota truncata*, and other fossils. The highest beds seen are purplish grits and conglomerates, the exposed thickness of the Straiton Group being about 900 feet.

The highest beds referable to the Wenlock Series are well exposed in Lanark, where they are no less than 2200 feet thick (see table below), and yet do not include any beds comparable to those near Straiton; hence there seems to be a gap in the succession, and the full thickness of this series in Scotland is not yet known.

Ludlow Series.—These beds are not found in the main belt nor in the Girvan district, but only in Lanark and the Pentland Hills, where the following succession has been recognised:—

		Feet.
Downtonian Beds	{ Chocolate-coloured sandstones	2700
	{ Conglomerate with quartz pebbles	
	{ Mudstones and shales with fish and eurypterids	
	{ Red and yellow sandstones and mudstones	
Ludlow .	Red and green shales with <i>Platyceras simulans</i>	1480
Wenlock Beds	{ Brown sandstones with <i>Orthoceras</i>	2200
	{ Green and grey shales and mudstones	
	{ Massive sandstones and grits	
	{ Green, red, and purple shales with eurypterids	
	{ Starfish, crinoids, and corals	

The beds which are bracketed as having a thickness of 2700 feet were formerly grouped with the Old Red Sandstone, but are regarded by the Geological Survey as the equivalents of the Downton and Ledbury Beds. They include a band of shales which has yielded many remains of fish and Merostomata. The fish fauna is of great interest, as two of the genera belong to a family which has hitherto been known only from scales; these genera are *Thelodus* and

Lanarkia, belonging to the family *Cælolepidæ*, which, according to Dr. Traquair, are nearly related to the *Pteraspida*, although they have superficial resemblances to the sharks. Other new genera found in these beds are *Ateleaspis*, *Birkenia*, and *Lasanius*. The Merostomata include species of *Stylonurus* and *Eurypterus*, and the Crustacean *Ceratiocaris* is also present. The underlying Ludlow shales have yielded the earliest British arachnid in the form of a scorpion (*Palæophonus*), a genus first described from remains in the Silurian of Gottland (Sweden).

5. Ireland

Rocks of Silurian age succeed the Ordovician Series in many parts of Ireland; they may be described as exhibiting two different facies, the one comparable with the Scotch type and the other with the Llandovery-Wenlock type.

Eastern Facies.—Valentian rocks of the Birkhill-Gala type occur in the north-eastern and central counties, and probably they extend under the whole of Central Ireland down to the coasts of Clare and Waterford. Rocks having the same general character as the Birkhill shales and Gala Series of Southern Scotland range through the counties of Down, Armagh, Monaghan, and Cavan; it has, in fact, been found that the greater part of the tract which was coloured as "Lower Silurian" on the older geological maps of Ireland consists of Valentian rocks.¹⁹ The older beds (Birkhill shales) occur chiefly along the north-west border of the area, and have yielded the characteristic graptolites, *Diplograptus folium*, *Monograptus gregarius*, *M. Sedgwicki*, and *Rastrites maximus*. South of this zone are rocks of Gala type containing *Monograptus priodon*, *M. turriculatus*, and *M. riccartonensis*, while in County Louth there are rocks comparable to the Riccarton Group with Wenlock fossils.

Graptolitic Valentian Beds have also been found near Pomeroy in Tyrone, and again far to the south-west in Queen's County, Clare, Tipperary, and Limerick, where large inliers of Silurian rocks are brought up by anticlinal domes from beneath the Old Red Sandstones.

Western Facies.—In the district lying between Lough Mask and Killary Harbour (County Mayo), and again in the Dingle promontory of Kerry, there are thick developments of the whole Silurian System, and here the deposits give evidence of the close proximity of land.

In Mayo, north of Killary Harbour, Llandovery sandstones rest on Arenig Beds, but south of that inlet they overlap the Ordovician

Fig. 59.—DIAGRAMMATIC SECTION ACROSS THE PENTLAND HILLS. Distance about 6 miles.

m. Edge-coal Series.
c. Upper Old Red.
c and *D.* Lower Old Red Sandstone.
DD. Flows of diabase and andesite.

Fig. 60.—SECTION ACROSS THE DINGLE PROMONTORY (after Professor Hull). Distance 6½ miles.

e. Upper Old Red Sandstone.
d. Purple slates } Gleugarriff Beds.
c. Green grits }
b. Croaghmarbin Beds (Ludlow)
a. Ferriters Cove Beds (Wenlock).
f.f. Faults.

and rest directly on the Archæan rocks, their base being a breccia consisting of angular lumps of quartz and schist. Above this are red mudstones and a band of calcareous grit with Upper Llandovery fossils succeeded by a massive conglomerate consisting mainly of rounded pebbles and boulders of quartzites like those of Connemara. Then comes a thick series of coarse grits alternating with green sandy slates which have yielded a few fossils of Wenlock species, *Monograptus riccartonensis* and *M. vomerinus*. These beds may be about 2000 feet thick. Above them are the Salrock Beds, dull red and green shales, with thin bands of grit, and having a thickness of about 3000 feet. They contain a small species of *Lingula* (*L. Symondsi*) with *Pterinea retroflexa* and *Modiolopsis complanata*. They probably represent the greater part of the Ludlow and Downton Beds.²⁰

In the Dingle promontory the ascending succession is as follows²¹ (see Fig. 60):—

- (1) Smerwick Beds, a thick series of red, green, and yellow sandstones with bands of conglomerate; fossils rare, but *Atrypa hemispherica* and others have been found.
- (2) Ferriters Cove Beds, greenish sands and shales with bands of red sandstone; these beds are 2500 feet thick and contain fossils of Wenlock species.
- (3) Croaghmarhin Beds, hard brown calcareous grits with *Pentamerus Knighti* and other Ludlow fossils. These dip southward at a high angle and pass below a great series of green and purple grits and shales which are known as the Glengarriff grits, and believed to be of Devonian age.

Here, also, there are evidences of contemporaneous volcanoes. The best sections are in the cliffs near Clogher Head, where the interstratification of the lavas and tuffs with the fossiliferous Wenlock Beds is beautifully exposed. Sir A. Geikie describes the lavas as nodular felsites, the nodules being from the size of a pea to that of a hen's egg, and the associated pyroclastic rocks vary from fine pumiceous tuffs to coarse agglomerates. One of these beds is a coarse agglomerate about 15 feet thick, consisting of large blocks of felsite embedded in calcareous sandstone which is full of the casts of brachiopods, crinoids, and corals. The district has been recently examined by Messrs. S. H. Reynolds and C. T. Gardiner, who found that some of the lavas are rhyolites, and that all are of acidic character.²²

From these facts we learn that a volcano existed in this part of the Silurian Sea, and that from time to time it burst into eruption, pouring forth lava streams and ejecting showers of stones and ashes,

which fell into the surrounding sea and were spread out on its floor, while between each epoch of eruption marine sediments of the usual kind were greatly accumulated. The part of the sea in which these deposits were formed was probably not very far from the shores of a continent occupying a large area in what is now the Atlantic Ocean.

D. CONTINENTAL EQUIVALENTS

Rocks of Silurian age occur in Scandinavia, Russia, Poland, Thuringia, Bohemia, Carinthia, the Alps, Belgium, France, and Spain. We can only refer to the more important areas.

1. *Scandinavia*

Undisturbed and unaltered Silurian strata not only occur in the same parts of Norway and Sweden, and succeed those of the Ordovician System (see p. 146), but they also form the island of Gottland in the Baltic, which thus becomes a link between the Swedish and Russian areas (see map, p. 66).

The Silurian Series exhibits several different facies in different parts of the Scandinavian region, and shows great variation in thickness. It is most fully developed in Scania, where sedimentation in the form of graptolitic shales continued throughout the whole of Valentian and Wenlock times, a bed of limestone only occurring at the top of the system, the full thickness of which is there about 4000 feet. This great series is divisible into zones which can be correlated with those of Great Britain.

In the Christiania district the deposits are very different, consisting of an alternating series of limestones and shales, and the total thickness is not much over 1200 feet, but is not complete at top.

In Oland and Gottland, again, to the east the facies is essentially calcareous, shales prevailing only in the lowest part, and the whole system is condensed into a thickness of something less than 200 feet in Gottland. The base, however, is not seen, though the sequence extends down as low as the equivalent of our May Hill sandstone (Upper Llandovery), neither do the highest beds come into these islands.

The Gottland limestones are shallow-water and not deep-water deposits.²³ They consist largely of crinoidal limestones, but these are replaced locally by beds which are so largely composed either of Stromatoporoids or Corals (or of both) that they have clearly been formed by the growth of these organisms *in situ*. There

TABULAR VIEW OF THE SILURIAN SYSTEM IN NORWAY AND SWEDEN

Christiania District.	Scania (after Tullberg).	Gottland (Hedström and Munthe).
<p>Unconformity.</p>	<p>Red and yellow sandstones with <i>Beyrichia Kladeni</i> and <i>Grannmysia cingulata</i>, 1000 feet.</p> <p>Grey limestone and green shales, 200 feet.</p>	<p>(Asoceras limestone, replaced locally by crinoid or marly limestone, 30 feet.</p> <p>Crinoidal limestone, locally rich in <i>Stromatopora</i> and <i>Megalomus</i>, 20 feet.</p> <p>Soft marly limestone with <i>Ilionia</i> (= <i>Lucina</i>) and <i>Spongiostroma</i>, 15 feet.</p> <p>Sphaerocodium limestones, with Oolite and locally sandstone, 40 feet.</p>
<p>Grey limestone with <i>Orthoceras cockleatum</i>, 70 feet.</p> <p>Limestones and shales with <i>Monograptus ludensis</i>, 700 feet.</p>	<p>Cardiola Shales with beds of limestone, 2000 feet, with <i>Monograptus colonus</i>, <i>M. dubius</i>, <i>M. scanicus</i>, <i>M. Nillissoni</i>, and <i>Cardiola interrupta</i>.</p>	<p>The Dayia flagstone, a thin layer 4 inches thick, full of <i>D. navicula</i>.</p>
<p>Marly shales with graptolites, 125 feet.</p>	<p>Cyrtograptus shales, divided into seven zones, 500 feet.</p> <p>a. zone of <i>Cyrtograptus Carruthersi</i>.</p> <p>b. " "<i>rigidus</i>.</p> <p>c. " "<i>Monograptus Riccartonensis</i>.</p> <p>d. " "<i>Cyrtograptus Murchisoni</i>.</p> <p>e. " "<i>Lapworthi</i>.</p> <p>f. " "<i>spiralis</i>.</p> <p>g. " "<i>Græve</i>.</p>	<p>Marly shales with thin layers of limestone, <i>Mon. priodon</i>, <i>Pentamerus galatæus</i>, <i>Rhynch. borealis</i>, and Corals, about 30 feet.</p>
<p>Limestones with <i>Pentamerus oblongus</i> and <i>Favosites</i>, 300 feet.</p> <p>Conglomerate at base.</p>	<p>Rastrites shales in five zones characterised by species of <i>Rastrites</i>, <i>Monograptus</i>, and <i>Diplograptus</i>, 400 feet.</p>	<p>Stricklandinia marl (only seen near Wisby). <i>Stricklandinia tirata</i>, <i>Illenus barriensis</i>, etc., 50 feet.</p> <p>Base not exposed.</p>

are also beds of oolite and of marly limestone which are rich in *Spongiostroma*, a kind of calcareous alga, and thin bands made up of *Sphaerocodium*, which is another alga of solid globular form.

The succession of beds found in these three districts is given in an abstract form on p. 182, the figures 1, 2, 3 indicating the equivalents of the Valentian, Salopian, and Downtonian Series.

From the above account it will be seen that the Silurian of Gottland is quite an abnormal development of the system, and as such is not at all suitable to be taken as its typical facies. Hence the fashion which has come into vogue among continental geologists of using the term *Gothlandian* instead of Silurian is unfortunate and unnecessary.

It will be noticed that the equivalents of our Llandovery and Wenlock Beds are of comparatively small thickness, and that throughout the Scandinavian region the larger part of the sediments belong to the time of our Ludlow Beds with representatives of the Downtonian in Scania.

The highest beds are most fossiliferous in the Ramsåsa district of Scania, where they are often full of *Leperditia inæqualis* and *Tentaculites*. *Homalonotus Knighti*, *Phacops Downingiæ*, *Spirifera elevata*, *Pterinea retroflexa*, and a *Pterygotus* also occur.

2. Russia

The Gottland type of the system is found again on the Russian side of the Baltic in Esthonia and Livonia, the beds having clearly been once continuous across the intervening space. From the following table it will be seen that they are very little thicker than in Gottland, when allowance is made for their forming a more complete succession both at top and base.²⁴

		Feet.
3	Grey and yellow limestones with <i>Eurypterus Fischeri</i> , <i>Hemiaspis rugosa</i> , <i>Platyschisma helicites</i>	60
	Dolomite and marls, with a Wenlock fauna	60
2	Limestone with <i>Pentamerus estonus</i> and <i>Illænus barriensis</i> , passing into a coralliferous limestone	50
	Raikull Beds with few fossils (<i>Phacops elegans</i>)	100
1	Limestone largely composed of <i>Pentamerus borealis</i>	30
	Joerden Beds—shales and marls with <i>Encrinurus punctatus</i> , <i>Rhynchonella affinis</i> , and corals	25
		<hr/> 325

These beds pass southward beneath the Devonian Series, and when the Silurian reappears in Russian Poland near Kielce it presents a very different facies. The sequence has not yet been completely worked out, but consists in the lower part of shales

which seem from their graptolites to include representatives of zones from the horizon of the Tarannon shales to the Lower Ludlow (*Climacograptus*, *Mon. priodon*, *Mon. colonus*), succeeded by arenaceous beds (grauwacke) containing *Beyrichia Klædeni* and *Spirifer elevatus*. Above these are sandstones, some of the beds containing remains of Placoderm fishes and others Spirifers.

3. Bohemia

Passing now to Central Europe we still find in Bohemia a concentrated and largely calcareous facies of the Silurian with a very rich fauna, the limestone beds being crowded with species of Cephalopods, Trilobites, Corals, Brachiopoda, and Mollusca of various kinds. Some of the species are identical with those of Britain and Western Europe, but many are different, though for the most part belonging to the same genera. The beds which represent the Silurian System are all comprised within the stages E and F of Barrande, the succeeding stages G, H, which he included in the system, having since been relegated to the Devonian (see Fig. 45 and p. 221).

Barrande divided his stage E into two parts, E₁ comprising all the shales and E₂ the overlying limestone, but these do not correspond with palæontological subdivisions. Moreover, the highest beds of shale are very calcareous and contain large spheroidal limestone-balls or concretions, while layers of shale containing *Monograptus colonus* are interbedded with the overlying limestones. The succession with Barrande's grouping is:—

	Feet.
F ₁ . Black nodular limestone, with graptolites and other fossils . . .	150
E ₂ . Grey limestones in thick beds with occasional layers of shale (many fossils)	400
E ₁ . { Calcareous shales with <i>Mon. colonus</i> and <i>Cyrtograptus Lundgreni</i>	200
{ Black shales with <i>Cyrtograptus Murchisoni</i>	
{ Shales with <i>Mon. turriculatus</i>	
{ Shales with <i>Rastrites peregrinus</i>	
	750

The two lower zones are Valentian, the black shales correspond with our Wenlock shale, and the calcareous shale may be equivalent to the Wenlock limestone. The overlying limestones must represent the whole of the Ludlow Series, for they contain a mixture of Wenlock species of corals and brachiopods with such essentially Ludlow forms as *Pentamerus Knighti*, *Dayia navicula*, and *Monograptus colonus*, as well as a host of peculiar trilobites, lamelli-branches, gastropods, and cephalopods.

F₁ has until recently been regarded as Devonian by German geologists, but the most recent study of the beds and their contents, by F. Seemann,²⁵ has shown that it is more intimately connected, both stratigraphically and faunally, with the top of Stage E than with the beds above. Thus it contains graptolites, *Mon. colonus*, *M. priodon*, *Callograptus dichotomus*, and others, with *Orthoceras subannulare* and other species, and lastly, no *Goniatites* have been found in it. Seemann, therefore, regards this black limestone (F₁) as the top of the Silurian Series, and as forming to some extent a passage from the Silurian to the Devonian. It is, however, clearly marked off from the overlying white and red limestones which, in his opinion, form the base of the Devonian System (see p. 222).

The fauna of the thick mass of limestone forming Stage E is a very large one, including no fewer than 183 species of trilobites belonging to the genera *Acidaspis*, *Arethusina*, *Phacops*, *Proetus*, *Ilwenus*, *Lichas*, *Cyphaspsis*, *Cheirurus*, *Sphaerexochus*, etc. Of *Orthoceras* there are 250 species, and of *Cyrtoceras*, 150. Lamelli-branches are very numerous, and include the genera *Dualina* (100 sp.), *Panenka* (84 sp.), *Cardiola* (65 sp.), *Lunulicardium* (85 sp.), *Paracardium*, *Præcardium*, *Kralovna*, *Pterinea*, *Vlasta*, *Redonia*, and *Præluca*.

4. Germany

In Thuringia there is again a normal succession up to a zone of *Mon. colonus*, above which there appears to be a break in the sequence; and in the Kellerwald the case is similar, but there shales with *Cardiola interrupta*, *Monograptus*, and *Cyrtograptus* are succeeded by beds with *Phacops*, *Harpes*, and *Hercynella* before they are cut off by the unconformity.

In the Hartz Mountains, however, the stratigraphy is very different. There the oldest rocks exposed are a thick series of grits, mudstones, and shales, with some limestones which seemed to contain a mixed fauna of Silurian and Devonian forms with graptolites. By Beyrich and Lossen they were called the *Hercynian* and were regarded as an intermediate series between the Silurian and the Devonian Systems, but recent researches have shown that the central core of the range is a dislocated and faulted mass or complex, and that large parts of it are really Silurian while others are Devonian. To the Silurian must be referred the greywacke of Tanne, and the black limestones of the Tannenthal, which contain *Cardiola interrupta*, as well as the *Monograptus* slates of Wieda; though these seem to overlies beds with Devonian fossils, and were formerly regarded as the highest member of the series.

5. *Belgium*

Silurian rocks of a normal character are only exposed in the same valleys as disclose those of Ordovician age (see p. 145). The succession according to the most recent researches of Professor Malaise is as given below :—²⁶

Dark slates with *Monograptus colonus* and *M. Nillssoni*.

Sandy slates with *Mon. vomerinus*, *Cyrtograptus Murchisoni*, and *Cardiola interrupta*.

Flagstones and shales with *Mon. bohemicus*.

Black slates and quartzites with *Climacograptus normalis*.

Grey slates with *Phacops Stokesi* and *Halysites*.

It will be noticed that nothing above the horizon of the Lower Ludlow is exposed, but higher beds probably exist under the cover of newer deposits. The Silurian, however, must thin out southwards, for no such beds occur in the Ardennes, where a series known as the Gedinien, and generally regarded as Lower Devonian, rests unconformably on Cambrian rocks.

6. *France*

Silurian sediments occur in several parts of France, but generally present a shaly facies with small developments of limestone and are not rich in fossils. The most complete sequence of zones yet recorded is that of the west of Brittany (Crozon peninsula), where M. Kerforne has been able to recognise the succession of graptolite zones given in the table below.²⁷

West.	East.
Shales with <i>Bolbozoe</i> .	
,, with <i>Monograptus colonus</i> and <i>Orthoceras</i> in nodules.	? White Limestone of Erbray.
,, with <i>Mon. Salweyi</i> .	Black limestone of Briasse with <i>Mon. colonus</i> and <i>M. vomerinus</i> .
,, with <i>Mon. colonus</i> .	Shales with layers of calcareo- siliceous nodules, <i>Cardiola inter-</i> <i>rupta</i> , and species of <i>Panenka</i> , <i>Dualina</i> , etc.
,, with <i>Mon. Flemingi</i> .	Shales with <i>Cyrtograptus gein-</i> <i>tizianus</i> .
,, with <i>M. riccartonensis</i> .	Cherts with <i>Radiolaria</i> and shales with <i>Rastrites</i> and <i>Mon. lobiferus</i> .
,, with <i>Cyrtograptus</i> .	Sandstones without fossils.
,, with <i>M. convolutus</i> .	
,, with <i>Rastrites Linnæi</i> .	

In the central and eastern parts of Brittany, as well as in Mayenne and Anjou, a similar set of beds is found, though there are some lithological differences, and the graptolite zones have not yet been worked out. The two areas are compared above.

The thickness of this series of beds has not been estimated because of the frequent plications. There is also some doubt about the position of the Erbray limestone which contains some Devonian species, such as *Spirifer Decheni*, *Cryphaeus pectinatus*, and at the top *Harpes venulosus*.

In Normandy (Cotentin) the Silurian similarly consists of sandstone at the base succeeded by black carbonaceous shales (ampelites), the zonal details being at present unknown.

In Southern France (Languedoc) the Silurian presents a series of black shales and limestones about 650 feet thick. The lower part yields *Mon. priodon*, *M. Flemingi*, and higher up *M. colonus* and *M. bohemicus*. Black limestones at the top contain *Cardiola interrupta*, *Slava bohémica*, *Maminka comata*, and other Bohemian species (of E 1 and 2) with numerous fragments of *Orthoceras*, the fauna being of essentially southern type.

7. Pyrenees, Spain, and Portugal

In these countries the Silurian has for the most part an argillaceous facies like that of Brittany. In the Pyrenees it consists of black carbonaceous shales containing graptolites of Valentian and Wenlock species, but there are some calcareous shales, and in the Haute Garonne a black limestone contains several species of *Orthoceras* with *Monograptus priodon*.

In Catalonia there is a more complete succession, as below :—

Black calcareous shales, *Mon. colonus*, *M. Nilssoni*.

Soft black shales with *M. priodon*.

Black nodular shales with *M. turriculatus*.

Pale shales with *M. proteus* (Valentian).

A similar succession is found in Portugal (Alentejo and Barrancos), where the top bed is a thin band of limestone comparable to that of Rozan in Brittany.

E. CONDITIONS OF DEPOSITION

The general geographical conditions over Northern and Western Europe during the earlier part of Silurian time seem to have been similar to those prevailing in the Ordovician period. There was the same mass of continental land in the Atlantic area, along the borders of which thick deposits of sand and mud were accumulated, but there seems to have been more land over Central England and in the area of the North Sea, for it was probably from such land that the great mass of arenaceous material forming the Wenlock

Series of North Wales and Westmoreland was derived (see *Building of the British Isles*, 3rd edition).

The much greater thickness of Silurian deposits in Norway and Scania (as compared with the underlying Ordovician) also testifies to the nearer presence of land. There was, however, the same open sea over the Baltic area wherein little but limestone was deposited. In the North British area, too, the same strip of comparatively deep water persisted for a time with small sedimentation, though after the epoch of the Birkhill shales the whole British area received a large share of the detritus carried off the land which lay to the north and north-east of it.

The Silurian Sea probably extended over the same parts of the European region as were covered by that of the Ordovician period, but the land of Ardennes and the Rhine provinces, which may have existed in Ordovician time, becomes much more of a certainty in Silurian time. Thus in Belgium the Silurian extends southward to the Crête du Condroz, which separates the basins of Namur and Dinant, but must be overlapped farther south by the Devonian, for it does not emerge on the Cambrian areas of Rocroi and Stavelot (see Fig. 70, p. 216). Passing eastward we find the Devonian rocks forming a continuous band through the Eifel, Hunsruch, and Taunus districts, and resting near Frankfort on Cambrian exactly as they do in the Ardennes.

Southward the land probably included the Odenwald and the Schwarz Wald of Baden, together with the Vosges district on the western side of the Rhine, where a patch of Devonian lies directly on the crystalline Archæan rocks, and no Silurian or Ordovician occur. It may have extended still farther south into Switzerland, but of this there is no actual evidence. The region above indicated measures about 230 miles each way, *i.e.* from west to east and from north to south, so that it probably included an area of over 70,000 square miles, which is nearly as large as England.

Silurian strata are not found again till we go as far east as the Carnic and Carinthian Alps in Austria, and as far south as Sardinia, but this is probably due to their concealment by newer rocks, and it is very likely that the Silurian Sea was continuous from the south of France (Pyrenees and Languedoc) through Northern Italy to Carinthia, Styria, and Bohemia.

It is noticeable that in Southern Europe, *i.e.* in Languedoc, Pyrenees, Spain, the Carinthian Alps, and Bohemia, the fauna found in the Silurian strata is very different from that in the more northern areas; so that two distinct life provinces seem to have existed at this time in the European region.

The conditions of deposition which prevailed in this Silurian

Sea of Western and Central Europe seem to have remained uniform for a considerable time and with little change except that of a slow subsidence ; so that little but shale was deposited, while here and there beds of limestone were accumulated, especially in the north-east. During the later part of the period crust movement took place, causing elevation and raising much of the northern part of the region above the level of the sea.

With regard to the composition and construction of the Silurian deposits some interesting questions present themselves, especially in connection with the limestones. These often consist of a varied assemblage of organic remains, all the creatures then living in the sea which possessed calcareous shells or structural parts contributing to their formation, but occasionally some particular class of animals, or even one particular species, flourished in such numbers at certain places that their remains constitute almost the entire mass of the resulting bed of limestone.

Thus in some parts of the sea-floor there must have been fields of Crinoids, growing in myriads as they do now in parts of the Caribbean Sea. By the growth and death of successive generations of these fixed "stone lilies," and by the subsequent disintegration of the stems, cups, and arms, beds of crinoidal limestone were slowly accumulated.

In other places certain species of Brachiopoda flourished in such numbers that they must have occupied the sea-floor almost to the exclusion of other creatures, and their remains consequently form a Brachiopod limestone. Occasionally, too, one species so predominates over the others as to be the main constituent of the limestone, as in the case of the *Pentamerus borealis* limestone of Russia (see p. 183).

Other important components of Silurian limestones are Stromatoporoids and Corals which often occur together, but sometimes separately form the chief constituent of a bed or mass of limestone. Some coralliferous limestones are of such a nature that it has been imagined they were coral-reefs of the same kind as those built up by corals at the present day. This, however, is very doubtful for the following reasons.

In the first place, modern coral-reefs are either shore-formations resting unconformably on other rocks (fringing reefs), or they are steep-sided masses of limestone built up in the open sea with deep water on one or both sides of them ; and in areas of subsidence such reefs often reach to a great vertical height from the level from which they started. Now the only ancient coral-reefs that are likely to have been preserved are those which had been formed in areas of subsidence, where their lower parts would be flanked and

protected by deposits of marly limestone composed of coral mud and the remains of other organisms. If such an ancient reef were subsequently raised and truncated by marine erosion and finally preserved as part of the earth's crust, we should have a mass of unstratified reef-rock sharply defined on all sides, from the surrounding beds, and probably of great vertical height in proportion to its horizontal extension. It would not form a lenticular mass nor would it pass into other kinds of limestone.

Again the corals which build up such reefs at the present day belong to families which did not exist in Palæozoic seas, and only made their appearance in those of Triassic time. Corals of the single cup-shaped form are not likely to have been reef-builders, and though there were compound corals in the Palæozoic seas, such as *Heliolites*, *Favosites*, *Pachypora*, and *Alveolites*, they belong to the Alcyonaria, and though the living genus *Heliopora* lives on coral-reefs, no reliable inference can be drawn from this fact with respect to the habit and growth of *Heliolites* and others; we can only judge from what can be seen of their mode of occurrence in stratified rocks.

The other group of animals which has been credited with reef-forming capabilities are the *Stromatoporidae*, which are not corals nor Actinozoa of any kind, but are believed to have been Hydrozoa allied to the modern *Millepora*. They formed massive hemispherical or irregular globular growths of concentric laminæ, and varied in size from a few inches to masses of 3 or 4 feet in diameter. They were sometimes so abundant as to be the principal constituents of thick beds of limestone, which on account of the size of the component masses are often unstratified; thus they certainly formed submarine banks, but such banks are not "reefs."

The beds of coralliferous limestone which occur in the Silurian and Devonian strata of Britain, France, and Germany do not present the aspect of coral-reefs. They are merely lenticular beds or masses, of greater or less horizontal extent, and are often interstratified with shales or occur as bands in a mass of crinoidal limestone. Such a mode of occurrence proves that they were formed on a sea-floor in the ordinary way under a certain depth of water. The corals seem in some places to have formed fields or groves, like those of some modern species of Crinoidea, and the resulting limestone is unstratified, but such limestones must not be called reefs because there is no evidence that they were ever built up to the surface of the sea.

Limestones which have a greater resemblance to coral-reefs occur in Sweden, and some are beautifully exposed in the cliffs of the island of Gottland, where they can be seen to terminate in some

cases abruptly against another kind of limestone. The Swedish geologists call these beds *reefs*, and apply the term not only to such beds as are largely made up of corals, but also to those of which the principal constituents are Stromatoporoids or Bryozoa. Thus, writing of the *Ascoceras* limestone, Munthe says, "It may be considered as a reef-limestone formed chiefly of Stromatopora and of large fragments of Crinoids with marly sediment to fill the interspaces," and it should be noted that the Cephalopod *Ascoceras* is common in this limestone.

Good descriptions and photographs of these beds are given in the livret-guides provided for the Geological Congress at Stockholm in 1910 and from them it is plain that by the term "reef-limestone" the writers merely mean limestones composed of organic remains which have been accumulated in such a manner as to be unstratified. One such bed is shown to be overlain by stratified *Sphærocodium* limestone, another by crinoid limestone, and massive colonies of Stromatoporoids sometimes replace crinoid limestone. It is evident that all the beds were formed in shallow water where the sea-floor was swept by strong currents, to the action of which the frequent abrupt termination of some beds and their replacement by others may be ascribed, but it is very doubtful whether any of them ever formed a reef in the proper sense of that term.

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CHAPTER VIII

DEVONIAN AND OLD RED SANDSTONE SYSTEM

GENERAL CLASSIFICATION AND SUBDIVISIONS

WE have seen in the last chapter that, where complete sections are found, the Silurian rocks pass upwards into a thick series of red sandstones (England and Scotland), or into an equally thick series of grey and purple grits (Ireland). It will be shown in a future chapter that the marine Carboniferous rocks always rest upon a set of red and yellow sandstones, which often repose unconformably upon some of the more ancient Palæozoic strata. The marine fauna of the Silurian dies out at the base of the red sandstones, and when we reach the next marine fauna—that of the Carboniferous System—it is totally different from the preceding, so that a long period of time must have elapsed between the close of the Silurian era and the commencement of the Carboniferous.

The groups known as the Old Red Sandstone in England and Scotland, and the Glengariff grits or Dingle Beds in Ireland, are clearly some of the rocks which were formed in this interval; and if these were the only records of this portion of geological time, we might find it convenient to regard the whole of the beds which succeed the Silurian Series in conformable sequence as belonging to the Silurian System.

But these are not the only strata which are interposed between the Silurian and Carboniferous Systems. In Devonshire, and in many localities in Europe, there is a thick series of rocks containing a marine fauna which is evidently of intermediate age; further, in Germany the stratigraphical proof of their interposition between Silurian and Carboniferous rocks is complete. It is this marine series which must be taken as the normal type of the intermediate system, and any freshwater deposits which can be shown to be of the same age must be treated as local contemporaneous or homotaxial strata. In America also both types of the Devonian System are present.

The Devonian System was established by Sedgwick and Murchison in 1839 because they found in Devon a great series of rocks containing a special assemblage of fossils, and they divided this Devonian System into Lower, Middle, and Upper Groups; the convenience of this division has been confirmed by the researches of continental geologists.

Sedgwick and Murchison also took a leading part in the investigation of the European equivalents of these Devonian rocks, visiting the Rhenish mountains and indicating the existence of rocks containing a Devonian fauna in the Eifel district (1842). The more complete delimitation of the Devonian System was accomplished by F. Römer (1844), Von Dechen (1855), and the Sandbergers (1850-56). A little later came the important researches of Gosselet on the rocks of the Ardennes (borders of France and Belgium), where he established the same order of succession.

The Old Red Sandstone, which elsewhere occupies the position of the Devonian System, is believed to be of lacustrine or estuarine origin. It has been divided into a lower and upper series, with a middle series in Wales, but in Scotland there is a marked unconformity between the upper and lower series, and some are doubtful whether the upper series is really of Devonian age. It is probable that the Lower Old Red Sandstone may be correlated with the Lower Devonian, that the Middle Devonian was formed during the time represented by the unconformity in Scotland and Ireland, but how much of the Upper Old Red Sandstone is really of Devonian age will depend very largely on the results of further researches in North Devon and Ireland.

In dealing with the records of the Devonian period we shall describe the marine facies first, both in England and on the continent, and secondly the rocks known as the Old Red Sandstone.

I. THE DEVONIAN FACIES

A. THE MARINE FAUNA

As already mentioned, the Devonian fauna is intermediate in character between those of the Silurian and Carboniferous. Most of the characteristic Silurian genera become extinct in the Lower and Middle Devonian, while in the Middle and the Upper Devonian many genera which are prominent members of the Carboniferous fauna make their appearance. This is especially the case with the Brachiopoda, for all the Lower Devonian genera are found in the Silurian, while all those in the Upper Devonian range into the Carboniferous.

* The following is a brief account of the principal genera which

survive from the Silurian period, and of the more important genera which make their first appearance in Devonian rocks.

Among **Hydrozoa** the Stromatoporoids, which had some representatives in Silurian time, become specially abundant, and are characteristic of Devonian limestones. The principal genera are *Stromatopora*, *Stromatoporella*, *Actinostroma*, *Parallelopore*, *Amphipora*, and *Stachyodes*.

Among **Actinozoa**, *Acervularia*, *Alveolites*, *Arachnophyllum*, *Cystiphyllum*, *Pachypora*, *Favosites*, *Heliolites*, *Cyathophyllum*, *Plasmopora*, and *Syringopora* continue from the Silurian; and Zaphrentoid corals, which are rare in the Silurian, now become abundant. *Calceola*, *Heliohyllum*, and *Pleurodictyum* occur only in Devonian rocks. *Michelinia*, *Zaphrentis*, *Mesophyllum*, and *Phillipsastrea* appear and range into the Carboniferous.

Among **Echinoderma** the crinoids *Cyathocrinus*, *Ichthyocrinus*, and *Taxocrinus* continue. *Otenocrinus*, *Cupressocrinus*, *Hexacrinus*, *Melocrinus*, *Sphaerocrinus*, and *Rhipidocrinus* are specially Devonian genera. *Poteriocrinus* and *Haplocrinus* appear and survive. Of *Echinoids* certain archaic forms occur, such as *Lepidocentrus*, which has from five to eleven rows of interambulacral plates.

Among **Crustacea** trilobites are on the decline, though individuals are sometimes common. Representatives of twelve genera have been found in British Devonian rocks, *Acidaspis*, *Bronteus*, *Cheirurus*, *Cyphaspis*, *Lichas*, *Harpes*, *Homalonotus*, *Dalmanites*, *Phacops*, *Trimeroccephalus*, *Proetus*, and *Dechenella*. Of these *Phacops*, *Proetus*, *Bronteus*, and *Cyphaspis* are the commonest. The species of *Dalmanites* belong to the section or sub-genus *Cryphaeus*. The Ostracods *Beyrichia* and *Entomis* are also common.

Of **Brachiopoda** many of the Silurian genera survive and many new forms make their appearance; of the latter *Centronella*, *Davidsonia*, *Rensseleria*, *Megalanteris*, *Stringocephalus*, and *Uncites* are known in Britain as Devonian fossils only, while *Camarophoria*, *Productus*, *Strophalosia*, and *Terebratula* (*Dielasma*) range into the Carboniferous.

Of **Lamellibranchia** the following Silurian genera occur, but those with an asterisk die out within the period: *Ambonychia*,* *Myalina*, *Grammysia*,* *Leptodomus*, *Ctenodonta*, *Cardiola*,* *Cleidophorus*,* *Conocardium*, *Cyrtodonta*,* *Nucula*. *Pterinea* is very abundant, and the sub-genus with elongate wings (*Actinodesma*) is specially characteristic. The following genera appear and range into higher strata: *Aviculopecten*, *Ptychopteria*, *Cucullæa*, *Paralædon*, *Pleurophorus*, *Edmondia*, *Prothyris*, *Megalodon*, *Curtonotus*, *Myophoria* (?), and *Solenopsis*.

Among **Gastropoda** the following genera survive from the

Silurian and have many Devonian species: *Murchisonia*, *Pleurotomaria*, *Euomphalus*, *Straparollus*, *Platyceras*, *Loxonema*, *Macrochilina*, and *Bellerophon*. Besides these *Cyclonema*, *Callonema*, and *Eunema* occur, but die out within the period. *Scoliotoma* and *Philoxene* are Devonian only; *Naticopsis* and *Porcellia* appear and range upward.

Among **Cephalopoda** the following continue: *Orthoceras*,

Fig. 61.—GROUP OF DEVONIAN FOSSILS.

- a. *Bronteus granulatus*.
b. *Bront. granulatus* (pygidium).
c. *Calceola sandalina*.

- d. *Stringocephalus Burtini*.
e. *Pleurotomaria aspera*.
f. *Clymenia striata*.

Cyrtoceras, *Gyroceras*, *Poterioceras*, *Gomphoceras*, and *Trochoceras*. The last genus becomes extinct. The Ammonoidea make their first appearance and are represented by *Clymenia*, *Bactrites*, and the Goniatiidae, of which the following genera occur: *Mimoceras*, *Anarcestes*, *Agoniatites*, *Gephyroceras*, *Tornoceras*, *Meneceras*, *Branco-ceras*, *Beloceras*, and *Prolecanites*. *Clymenia* is found only in the Upper Devonian.

Of **Pisces**, *Pteraspis*, *Cephalaspis*, *Drepanaspis*, *Coccosteus*, *Parexus*, and *Homosteus* occur.

Fig. 62.—GROUP OF DEVONIAN FOSSILS.

- a.* *Cystiphyllum vesiculosum*.
b. *Heliolites porosus*.
c. *H. porosus* (magnified section).
d. *Rhynchonella cuboides*.

- e.* *Spirifer Verneullii*.
f. *Murchisonia angulata*.
g. *Harpes macrocephalus*.
h. *Phacops latifrons*.

The following are some of the most characteristic fossils of each division as found in England, France, and Belgium.

Fossils of the Lower Devonian

<i>Actinozoa.</i>	<i>Pleurodictyum problematicum</i> , <i>Zaphrentis oolitica</i> .
<i>Echinoderma.</i>	<i>Cyathocrinus megastylus</i> , <i>Ctenocrinus decadactylus</i> .
<i>Brachiopoda.</i>	<i>Spirifer primævus</i> , <i>S. auriculatus</i> , <i>S. cultrijugatus</i> , <i>S. paradoxus</i> , <i>S. hystericus</i> , <i>Orthis arcuata</i> , <i>Chonetes dilatata</i> , <i>C. sarcinulata</i> , <i>Renssælia crassicosta</i> , <i>Leptaena laticosta</i> , <i>Rhynchonella daleidensis</i> .

Fig. 63.—GROUP OF UPPER DEVONIAN FOSSILS.

<i>b. Rhynchonella Partridgeæ.</i>	<i>e. Cucullæa unilateralis.</i>
<i>c. Ptychopteria damnoniensis.</i>	<i>f. Curtonotus elegans.</i>

<i>Lamellibranchia.</i>	<i>Pteria anisota</i> , <i>Pteria spinosa</i> , <i>Pterinea costata</i> , <i>Pt. (Kochia) capuliformis</i> , <i>Ctenodonta Krachtæ</i> .
<i>Crustacea.</i>	<i>Homalonotus armatus</i> , <i>H. Champernowni</i> , <i>H. gigas</i> , <i>Dalmanites laciniatus</i> .
<i>Gastropoda.</i>	<i>Bellerophon trilobatus</i> , <i>Platyceras fecundus</i> , <i>Macrochilina elongata</i> .
<i>Pisces.</i>	<i>Drepanaspis gemundensis</i> , <i>Coccosteus angustus</i> , <i>Pteraspis</i> .

Fossils of the Middle Devonian

<i>Hydrozoa.</i>	<i>Stromatopora concentrica</i> , <i>Actinostroma stellulatum</i> , <i>Amphipora ramosa</i> .
<i>Actinozoa.</i>	<i>Pachypora cristata</i> , <i>Phillipsastræa pengellyi</i> , <i>Mesophyllum damnoniense</i> , <i>Cyathophyllum cæspitosum</i> , <i>C. obtortum</i> , <i>C. hexagonum</i> , <i>Cystiphyllum vesiculolum</i> , <i>Alveolites suborbicularis</i> , <i>Calceola sandalina</i> , <i>Heliolites porosus</i> .

- Echinoderma.* Sphaerocrinus geometricus, Hexacrinus interscapularis, Cupressocrinus crassus.
- Crustacea.* Proetus batillus, Bronteus granulatus, B. flabellifer, Phacops Schlotheimi, Cyphaspis ocellata.
- Brachiopoda.* Atrypa reticularis, A. desquamata, Stringocephalus Burtini, Pentamerus brevirostris, Meristella plebeia, Spirifer undatus, S. speciosus, Uncites gryphus, Streptorhynchus umbraculum, Cyrtina heteroclita.
- Lamellibranchia.* Megalodon abbreviatus, Conocardium clathratum, Cypricardinia scalaris, Actinopteria placida, Rutotia elliptica.
- Gastropoda, etc.* Loxonema reticulatum, Macrochilina arcuatum, Murchisonia turbinata, M. coronata, M. bilineata, Pleurotomaria delphinuloides, Philoxene laevis, P. serpens, Porcellia bifida.
- Cephalopoda.* Agoniatites occultus, Anarcestes subnautilus, Mimosceras gracile, Maeneceras decheni, M. molarium, Trochoceras obliquatum, Orthoceras laterale, Gyroceras nodosum.
- Pisces.* Species of Heterosteus, Coccosteus, and Homosteus.

Fossils of the Upper Devonian

- Actinozoa.* Acervularia Goldfussi, A. pentagona, Chonophyllum perfoliatum, Phillipsastraea Hennahi.
- Echinoderma.* Actinocrinus Porteri.
- Crustacea.* Phacops granulatus, P. latifrons (also in Mid. Dev.), Entomis serrato-striata.
- Brachiopoda.* Spirifera Verneuxi, S. Urei, S. distans, Orthis interlineata, Strophalosia productoides, Rhynchonella cuboides, R. laticosta, R. letiensis.
- Lamellibranchia.* Ptychopteria damnoniensis, Cucullaea unilaterialis, Ctenodonta (Palaeoneilo) lirata, Myophoria deltoida, Prothyris scalprata, Aviculopecten nexilis, Cardiola retrostriata (Cardium palmatum), Posidonomya venusta.
- Gastropoda.* Loxonema anglicum, Pleurotomaria aspera.
- Cephalopoda.* Gephyroceras intumescens, Tornoceras simplex, Beloceras sagittarium, Clymenia undulata, Clymenia striata, Bactrites gracilis.

B. BRITISH DEVONIAN ROCKS

In Britain the only surface exposures of undoubted marine Devonian rocks occur in Devon, Somerset, and Cornwall; they occupy the northern parts of Devon and Somerset between Morte Bay and the valley of the Tone, as well as the outlying tract of the Quantock Hills, east of that valley. Dipping southward beneath the central Carboniferous area, they reappear in South Devon and North Cornwall (see map, Fig. 64).

The strike of these rocks is nearly due east and west, and this appears to be maintained in their subterranean extension through the south of England, for rocks with the same Devonian fossils

have been met with in borings beneath the Cretaceous Beds which underlie London and Essex. They are known to occur in the same position in Belgium, and they emerge again to the surface in the Ardennes, so there is every probability of their being continuous across the intermediate areas.

1. *Devon and Cornwall*

The Devonian rocks in England have been so crushed, plicated, and broken by faults that it is no easy matter to make out the original order of succession either in North or South Devon, and it is almost impossible to estimate their original thickness. It will be noticed that the section, Fig. 66, shows a general inclination of the beds towards the north, newer and newer beds coming on in that direction. This is the rule in South Devon and North Cornwall, and yet the prevalent dips actually observed and recorded on the maps of the Geological Survey are toward the south, which would lead one to infer a complete inversion of the beds. These dips, however, are those of the minor plications, for not only is the whole system flexured into a succession of curves, but each flexure is frilled into smaller plications.

The following account is compiled from the memoirs of the Geological Survey on the new map of Cornwall and South Devon, and from papers by Mr. W. A. E. Ussher, supplemented by some observations of my own; for North Devon the publications of Jukes, Etheridge, Hicks, and others have been consulted.

The rocks of both the northern and southern areas are divisible into Lower, Middle, and Upper Series, and in order to deal with each of these series separately we must first give a tabular view of the subdivisions which have been made in each area. In constructing this table a group of rocks occurring in North Devon and known as the Morte slates has been omitted, for reasons which will be mentioned, and because the correlation of the other groups is complete without them. On the map, Fig. 64, these Morte slates are marked as a separate tract of Lower Devonian.

Cornwall and South Devon.		North Devon.		
Upper	{ Summit not seen.	Pilton Beds.	Baggy Beds.	
	{ Styliola and Entomis slates.			
Middle	{ Calcareous slates and limestones.	Pickwell Down Beds.	Ilfracombe Beds.	
	{ South Devon limestones, with associated slates and tuffs.			
Lower	{ Staddon grits.	Hangman grits.	Lynton Beds.	
	{ Meadfoot Beds.			
	{ Dartmouth slates and			Foreland sandstones.
	{ Grampound Beds.			

Lower Devonian.—The recent work of the Geological Survey in Cornwall has shown that the basal boundary of the Lower Devonian crosses that county along an east and west line from Porth Towan on the west to near Tregony on the east, whence it bends southward to Veryan and Nare Head (see Index map, 4 miles to 1 inch, sheet 25). From this line northward to St. Evan, Bodmin, and Plymouth, the country is occupied by Lower Devonian grits and slates, interrupted only by the intrusive mass of granite which lies to the north of St. Austell and St. Blazey.

Along the line of boundary above mentioned Devonian grits and conglomerates rest unconformably on rocks which are either of Ordovician or Cambrian age; but these grits do not appear to be the oldest Devonian strata. The surveyors think that the Dartmouth slates are concealed beneath an overlap of the higher beds on to a sloping shore-line, and believe the conglomerates of Grampound, Probus, and Nare Head to be shore deposits belonging to the Meadfoot division of the series. The general structure of North Cornwall is expressed in Fig. 65, which indicates the supposed overlap and the series of monoclinal flexures by which the beds seem to be repeated, but the section must be regarded as merely a diagram of the theoretic structure of the area.

The Dartmouth slates form a thick series of purple, red, and green slates with frequent bands of hard and fine quartzitic grit such as are called quartzo-phyllades in France and Belgium. They seem to have a thickness of over 2000 feet, but the base has not been seen because it is not brought up in any of the anticlinal flexures. The general position of these beds, according to the view taken by the Geological Survey, is indicated in Fig. 65.

The only definite marine invertebrate yet found in this series is *Bellerophon trilobatus*, which is stated to be fairly common though badly preserved. Fish remains also occur belonging to the genera *Pteraspis*, *Cephalaspis*, and *Parexus*.

The Meadfoot Group is another set of slates and fine grits, but is distinguished from the Dartmouth slates by the colour of the beds, this being always dark grey. In the Looe district the lowest beds are hard grits and quartzites with bands of grey slate, and it is these beds which are believed to pass southward into the coarse grits of Grampound and Probus. The faults and plications are so numerous that the thickness may be anything from 500 to 1000 feet. The Meadfoot Beds are more fossiliferous than those below, but the specimens are seldom in good preservation. The following are some of those which have been determined:—*Pleurodictyum problematicum*, *Pachypora* (? *cristata*), *Spirifer primævus*, *Sp. hystericus*, *Orthotetes hipparionya*, *Stropheodonta gigas*, *Renssælleria*

Fig. 65.—DIAGRAM-SECTION THROUGH PART OF CORNWALL FROM TREGONY TO PORT ISAAC.

Distance about 24 miles.

- a. Upper Devonian.
 d. Middle Devonian.
 c. Meadfoot and Stadon Beds.
 b. Dartmouth slates.
 a. Older Palaeozoic rocks.
 G. Granite, F. Faults.

Fig. 66.—SECTION ACROSS SOUTH DEVON FROM DARTMOOR SOUTHWARDS.

Distance about 9 miles.
Drawn from a sketch-section by Mr. Ussher.

- 10, 11. Culm-measures.
 8, 9. Variegated and grey slates } Upper Devonian.
 7. Dark-grey slates }
 6. Ashprington Beds.
 5. Middle Devonian limestone.
 4. Eifelian slates.
 3. Stadon grits } Lower Devonian.
 2. Meadfoot Beds }
 1. Dartmouth slates }
 G. Granite of Dartmoor.

sp., and *Phacops Ferdinandi*. The place whence the beds take their name is Meadfoot Beach, east of Torquay, and near that locality they include bands of fossiliferous brown grit (originally calcareous), from which *Homalonotus armatus*, *Leptæna laticosta*, *Chonetes sarcinulata*, *Spirifer hystericus*, and *Sp. paradoxus* have been obtained.

The Staddon grits, which take their name from Staddon Point near Plymouth, are red and purplish-grey grits with intercalations of red shale and mudstone. Their outcrop is nearly continuous from St. Breock Downs to Plymouth, and thence eastward to the coast south of Brixham; they are brought in again to the northward around Paignton by a local anticline. At Torquay they are exposed on the Warberry and Lincombe Hills which form the centre of a complex and faulted anticline (see Fig. 67), and they have yielded a few fossils, among which are *Leptæna laticosta*, *Bellerophon trilobatus*, *Streptorhynchus umbraculum*, *Spirifers*, and species of *Orthoceras*, *Cyrtoceras*, and *Homalonotus*.

Passing now to North Devon the first point to be noted is the difference in the lithological character of the lowest beds. The Foreland sandstones occupy the position of the Dartmouth slates, and they contain remains of *Pteraspis*, but they are hard sandstones or grits, of red, brown, and grey colours, mostly of fine grain, but including some coarse and even pebbly beds. They were clearly deposited much nearer to a shore-line which must have lain in the space now occupied by the Bristol Channel.

The Lynton Beds consist chiefly of hard slates with some beds of grit and occasional calcareous bands, and are supposed to be from 1200 to 1500 feet thick. Fossils are fairly abundant, but in a bad state of preservation. The following have been recorded: *Spirifer primævus*, *Sp. hystericus*, *S. lævicosta*, *S. speciosus*, *Orthis arcuata*, *Chonetes sordida*, and *Orthotetes umbraculum*. These beds are succeeded by the Hangman grits, which consist of brown, green, yellow, and red sandstones with some coarse red and speckled grits in the upper part. They form the cliffs between Woodabay and Combe Martin Bay, and are probably more than 1500 feet thick. No fossils except a few casts in the highest beds have been found. The Hangman grits correspond in every way with the Staddon grits of South Devon, and the Lynton Beds as clearly represent the Meadfoot Beds.

The Morte slates have already been mentioned, and their position is shown on the map (Fig. 64), and in the section, Fig. 68. Jukes was the first to suspect the existence of a great fault along the southern boundary of the Morte slates,¹ but he imagined that these slates were of Carboniferous age, and that

Fig. 67. — DIAGRAMMATIC SECTION THROUGH THE TORQUAY AREA (a broken anticline). Distance $1\frac{1}{2}$ mile.

Fig. 68. — DIAGRAMMATIC SECTION ACROSS NORTH DEVON SHOWING THE APPARENT ORDER, BUT NOT THE TRUE POSITION OF THE NORTH SLATES. Distance about 15 miles.

the whole of the North Devon rocks were duplicated by the fault, the Pickwell Down Beds being a repetition of the Foreland Beds, and the succeeding beds on each side of the fault being comparable with one another. This view was combated by Mr. Etheridge,² who found it easy to show that the fossil evidence made it untenable, for the fossils of the Lynton Beds are unquestionably Lower Devonian, while all the fossils found in beds south of the Pickwell Down Group are with equal certainty of Upper Devonian or Carboniferous age.

When Mr. Etheridge wrote, no fossils had been found in the Morte slates, but in 1895 and 1897 Messrs. Hicks and Whidborne³ found fossils at several places along their outcrop, and the assemblage appears to indicate the existence of a Lower Devonian fauna. In the papers referred to Dr. Hicks stated his belief that not only is there a fault along the southern boundary of the Morte slates, but one along their northern border, that these slates are in fact thrust up between the two lines of fault, and that they are the oldest rocks in North Devon, but the final conclusion is not generally accepted. It is true that the Morte slates differ from any other slates in North Devon, for they are smooth and glossy, while the Lynton slates are mostly rough and gritty; still it is more probable that they are a facies of the Lynton slates than beds older than the Foreland sandstones.

The fossils referred to were obtained from Morte Bay and Mullacott on the coast, and from Treborough in Somerset. Some of the species are described as new (such as *Lingula mortensis*); some resemble Silurian forms, such as *Orthis rustica*; and others are Lower Devonian, e.g. *Dalmanites laciniatus*, *Strophomena tenuolata*, *S. explanata*, *Chonetes plebeia*, and *C. sarcinulata*.

Middle Devonian.—In South Devon this consists of a series of grey shaly slates in which masses of limestone are lenticularly developed, and in places both are partially replaced by volcanic materials—stratified tuffs and diabase lavas.

The chief interest centres in the limestones, and these are best known from their developments at Plymouth, Brixham, Torquay, Totnes, Ipplepen, and Oggwell. The lowest beds, however, are always grey shales, and under the lowest limestone near Torquay these have yielded *Calceola sandalina*, *Spirifer speciosus*, *Sp. curvatus*, *Atrypa reticulata*, and some other fossils. They evidently correspond with the beds known as Calceola shales in Belgium.

The limestones certainly occur on more than one horizon, and Mr. Ussher has classified them as lower and higher limestones.⁴ The lower set are generally dark grey or nearly black, are well bedded, and consist mainly of crinoid ossicles, beds containing corals

and Stromatoporoids only occurring at intervals and never being more than 3 or 4 feet thick, while the thickness of such bedded limestone may vary from 100 to 300 feet. Such limestones are typically developed round Dartington and Little Hempstead, near Totnes; they also occur at Ashburton, at Galmpton near Dartmouth, at Torquay, and Babbacombe. Their most characteristic fossils are: *Pachypora reticulata*, *Favosites fibrosus*, *Cyathophyllum cæspitosum*, *Cystiphyllum vesiculosum*, *Mesophyllum helianthoides*, and *Alveolites vermicularis*.

The higher limestones are of much lighter colour and often make beautiful marbles, being grey or nearly white, pinkish, or grey mottled with red. They are generally massive and unstratified and are frequently largely composed of Stromatoporoids, some masses of which are from 3 to 4 feet across; compound corals occur as scattered and generally broken lumps, the commonest being *Pachypora cristata* and *Heliolites porosus*.

These limestones in the Plymouth and Torquay districts pass up into beds which contain a mixture of Middle and Upper Devonian species. These are also massive but shelly limestones, the chief constituents being crinoids, small Stromatoporoids, broken corals and shells. Of corals the commonest are *Pachypora cristata*, *Alveolites suborbicularis*, and *Phillipsastrea* (*Smithia*) *Pengellyi*. Of shells there are *Stringocephalus Burtini*, *Rhynchonella cuboides*, *Pentamerus brevisrostris*, *Spirifer curvatus*, *Atrypa reticularis*, and *Cyrtina heteroclita*, with, less commonly, the trilobites *Bronteus granulatus* and *Cyphaspis ocellata*. The fauna of this limestone has been described and figured for the Palæontographical Society by the late G. F. Whidborne. The thickness of massive limestones near Torquay is probably over 200 feet.

In North Devon the Middle Devonian consists of a series of grey slates and flagstones with lenticular layers of earthy limestone. The lower part is sometimes called the Combe Martin Beds, but they are only the lower part of the Ilfracombe Beds and contain a similar fauna; the lower beds are rather more sandy and flaggy, while the higher beds are silvery-grey slates. The whole series is intensely plicated, compressed, and cleaved, the observable dips being generally those of isoclinal folds dipping southward so that the actual thickness of the series is nothing like so great as the breadth of basset-surface would seem to indicate, and may not be more than from 1000 to 2000 feet.

Like all the other divisions of the Devonian in North Devon and Somerset it occupies a continuous band or tract of country, crossing Exmoor and the Brendon Hills from west to east. It crops out again in the Quantock Hills, and presumably it and the

Lower Devonian had some extension to the northward, but both are absent above the Silurian outcrop in the Mendip Hills, which are only 17 miles north-east of the Quantocks.

Upper Devonian.—In South Devon at certain places, as for instance Plymouth, West Ogwell, and Chudleigh, the massive limestones pass up into red or pink limestone containing *Acervularia Goldfussi*, *A. pentagona*, and *Chonophyllum* with sometimes *Rhynchonella cuboides* and *Spirifer bifidus*. In other places a massive grey unfossiliferous limestone is succeeded by red shales with layers of nodular limestone containing the characteristic Goniatites (see p. 199) with *Cardiola retrostriata* and *Phacops cryptophthalmus*. These beds are succeeded by red and green shales in which the small Crustacean *Entomis serrato-striata* is often abundant, with occasionally the small bivalve *Posidonomya venusta*.

West of Dartmoor, in North Cornwall, these higher beds have a much greater development, occupying a broad tract of country extending from between Padstow and Boscastle on the coast round the north side of Bodmin Moor to the borders of Dartmoor between Tavistock and Bickleigh. They consist of grey, green, red, and purple shales in which impressions of the Pteropod *Styliola* are often abundant as also is the *Entomis*. Other fossils only occur locally, but quarries near South Petherwin have yielded a large fauna, the following being some of the species:—*Clymenia levigata*, *C. striata*, *Orthoceras Phillipsi*, *Tornoceras lineare*, *Ctenodonta antiqua*, *Cardiola retrostriata*, *Spirifer Verneuvilli*, *Orthis interlineata*, *Strophalosia subaculeata*, and *Phacops granulatus*.

In the cliffs on the west coast it has been possible to make out something like a regular succession in spite of faults and plications. The data on which this is based are given in the Survey memoir on the country round Padstow, but the following table is not a copy of that given in the memoir, as I have omitted the flaggy slates of Camel Quarry, which may be of Middle Devonian age and have separated the lower part of the "Striped Slates." The descending succession then reads thus:—

5. Purple, green, and variegated slates.
4. Dark slate and pillow lava.
3. Soft black slates with limestone bands (many fossils).
2. Grey slates and thin limestones and a fossiliferous band yielding many Cephalopoda.
1. Grey shales with scattered phosphate nodules, thin layers of limestone and of black grit.

The phosphatic nodules in the lowest beds contain *Conularia complanata*; the limestone of Dinas Head (in No. 2) contains black cherts with Radiolarian remains; while the overlying black slates

are full of *Tentaculites*, *Styliola*, and *Buchiola retrostriata*, and certain beds have yielded species of *Orthoceras*, *Bactrites*, *Tornoceras*, *Mimoceras*, *Anarcestes*, and *Agoniatites* with remains of *Phacops latifrons*, *P. granulatus*, and *P. levis*.

The variegated slates contain *Entomis serrato-striata* and *Posidonomya venusta*, and they occupy a syncline which forms an oval area around St. Minver and St. Kew.

Nothing which exactly corresponds to the Petherwyn fauna has been found on or near the coast, and it is thought that its stratigraphical position is above that of No. 5; its absence in the west being due either to an overlap of the basal Carboniferous Beds or to faulting.

In North Devon, on the other hand, there appears to be a complete succession, and the difficulty is to determine where the line of division between the two systems should be drawn.

The series has been divided into three stages, the lowest being the Pickwell Down Beds, a set of red, purple, brown, and green sandstones with intercalated bands of shale. They are traceable from Pickwell Down near Morte Bay to Wiveliscombe in Somerset, but the only fossils yet found are fish remains and fossil wood.

The Baggy Beds consist of green shales and yellowish sandstones and flags, and extend inland from Baggy Point, north of Croyde Bay, by Marwood and Sloly, where are quarries from which many fossils have been obtained, including *Ptychopteria damnoniensis*, *Cucullæa unilaterialis*, *Rhynchonella laticosta*, *Spirifer Verneuilli*, *Strophalosia productoides*, *Chonetes hardensis*, and plant remains (*Stigmæria* and *Knorria*).

The Pilton Beds consist of bluish-grey slates with thin bands of limestone and of sandstone. They stretch from Croyde Bay inland by Braunton and Pilton and are highly fossiliferous, containing among others *Phacops latifrons*, *Productus prælongus*, *Spirifer Verneuilli*, *S. Urei*, *Orthis interlineata*, *Strophalosia productoides*, *Aviculopecten nexilis*, *Loxonema anglicum*, and other Gastropoda. They appear to pass upward into the Lower Carboniferous shales, and the divisional line has not yet been fixed; but this point will be discussed on a later page.

2. The South of Ireland

The Devonian rocks of Southern Ireland have generally been treated under the head of Old Red Sandstone, but the more complete knowledge which we now possess of their equivalents in Devon, Cornwall, and Brittany makes it probable that they are

almost entirely of marine origin, and are really comparable with the Devonian Series of these more southern areas.

The upward passage from Silurian to Devonian is exhibited in the coast section of the Dingle promontory in Kerry, where the beds with Ludlow fossils are conformably overlain by grey, brown, and purple slates without fossils, followed by alternations of grey grits and slates, the grits at length predominating and forming a thick series of hard, massive green and purple grits.⁵ The whole of this Gritstone Series is perhaps 8000 feet thick, and is succeeded by slates of red and purple tints, with beds of conglomerate at Parkmore, which curiously enough enclose pebbles containing Silurian fossils. No other fossils have yet been found, and except for the occurrence of these derived pebbles, the whole of these slates and grits might be taken for a continuation of the Silurian rocks, so similar are they to the underlying fossiliferous series.

A similar set of green and purple grits occupies large areas to the south and south-west of Dingle Bay in the Inveragh and Dunkerron promontories, and in the districts of Killarney, Kenmare, and Glengarriff. It has generally been assumed that these "Glengarriff Beds" are the equivalents of the Dingle Beds, but Jukes was doubtful on the point, and Mr. McHenry is of opinion that the latter are entirely below the Glengarriff Beds. It is possible, however, that the actual base of the latter does occur in the Dingle promontory.

The great series known as the Glengarriff Grits consists of several thousand feet of alternating bands of fine-grained grit and slate. The lower part is mainly composed of green grits with subordinate beds of slate; while in the higher part purplish-red slates predominate over the grits. No minor subdivisions have yet been made, and no fossils have been found in them. The thickness of the whole series has been roughly estimated at 8000 feet, but when allowance is made for folds and faults it may prove to be much less than this figure.⁶

The beds have been subjected to such pressures that the shales are cleaved into slates, and the grits rendered nearly as hard as quartzites. They have also been thrown into a succession of regular anticlinal and synclinal folds which range east and west from the west coast of Kerry to the eastern part of Cork. The hard grits of the lower series, though exposed in anticlines, form long ranges of mountains because of their capacity for resisting subaerial erosion, while deep longitudinal valleys have been excavated through the purple slates and the still softer black slates which overlie them and come into the synclines (see map, Fig. 94, and section, Fig. 72).

In Kerry and the west of Cork there seems to be a complete upward sequence from the greenish grits through the purple slates to a series of grey and brown grits with intercalations of dark-grey slate, which group is known as the *Coomhola Beds*. These contain a marine fauna which is similar to that of the Baggy and Marwood Beds of North Devon, and they are succeeded by a set of dark-grey and black slates which resemble the Pilton Beds, but their fossils have not yet been collected with sufficient care to separate the Devonian and Carboniferous portions of the series. Fig. 69 is a copy of the section drawn by Jukes to illustrate the relative position of the beds near Glengarriff Harbour at the head of Bantry Bay.

Jukes could find no evidence of unconformity; but Professor Hull, going over the district in 1878-80, thought he could detect

Fig. 69.—SECTION NEAR GLENGARRIFF (Jukes). Distance about 2½ miles.

	Feet
e. Black slates with calcareous bands }	about 2000
d. Black and grey slates }	
c. Coomhola grits and slates	3000
b. Upper } Glengarriff grits	
a. Lower } Glengarriff grits	5000

an unconformity between the Coomhola Beds and the Glengarriff Series at Sneem near Kenmare.⁷ His section, however, is by no means convincing.

In the more recent revision of the country round Cork the Geological Surveyors⁸ have failed to find any evidence of a break between the two series, the Upper Glengarriff Beds in that district being succeeded by yellow sandstones and green shales which occupy the place of the Coomhola Beds, and are overlain by shales with Carboniferous fossils. It is true that these yellow sandstones are not the Coomhola Beds and do not contain marine fossils, but only fish and plants of Upper Devonian species. They are in fact the Kiltorcan Beds or Upper Old Red Sandstone of Kilkenny.

From the above account the student will understand that there are still several points to be cleared up in the geology of the south-west of Ireland, and in particular the exact relation between the Coomhola and the Kiltorcan Beds remains to be ascertained. If, however, we consider the sequence found in West Cork and Kerry by itself, we may regard it as a succession of presumably

marine Devonian rocks, including representatives of the Middle and Upper Devonian, while the lower series is either absent or still awaits recognition.

The correlation of the two areas may possibly be as follows :—

Ireland.	Devon and Cornwall.
Lower Carboniferous slates.	Lower Pilton Beds.
Coomhola Beds.	Baggy Beds.
Purple slates and grits.	Pickwell Down Beds.
Lower Glengariff grits.	{ Middle Devonian.
	{ Lower Devonian.

Finally the northern extension of this Devonian Series into Central Ireland must be briefly noticed. The Glengariff Beds appear at intervals in Limerick, South Tipperary, and Kilkenny, comprising a purple slaty series like the Upper Glengariff Beds, passing up into a yellow sandstone and shale series like that of Cork. In the Ballyhoura, Galty, and Knockmealton Mountains these beds rest unconformably on the Silurian, and hence it is probable that the whole Glengariff Series is similarly unconformable to the older formations, which constitute what may be called the "Caledonian" land. The position of this land is shown by the rapid thinning out of the Glengariff Series, and the overlap of the uppermost division on to the Silurian in Clare and the north of Tipperary. A similar overlap takes place to the north-east in Carlow, where the Kiltoran Beds overlap the lower beds on to the granite, and to the eastward in Waterford, where they lie directly on the Ordovician.

Of the Kiltoran Beds it need only be said that they thicken to the north and east, developing a thick mass of conglomerate at their base which has evidently been derived from the erosion of a land lying in those directions. In Waterford and Kilkenny this is overlain by reddish-brown sandstones succeeded by grey sandstones and red shales, above which are yellow sandstones and olive-green shales. These last are fossiliferous, containing the scales of *Coccosteus* and *Glyptolepis*, the bivalve *Archæanodon Jukesi*, which was supposed to be a freshwater mollusc but has since been found in association with marine Carboniferous Mollusca; there are also the remains of ferns, *Palæopteris hibernica*, *Sphenopteris Hookeri*, *Knorria*, and other plants.⁹

C. DEVONIAN OF THE CONTINENT

1. *France*

Marine sediments of Devonian age are found both in the north and south of France, but are most fully developed in the north-

west, Brittany, Normandy, and Anjou, and in the north-east in the region of the Ardennes. It will be convenient to begin with Brittany, which is the nearest to our own Devonian area. The western facies of the system is found in the basin of Finisterre, which extends from the Rade de Brest to Lanfains and Uzel north of Loudeac. For our knowledge of this area we are chiefly indebted to the labours of Professor C. Barrois, who has described the succession as consisting of three natural lithological divisions corresponding with differing bathymetrical conditions of deposition, *i.e.* shallow, deeper, and deep.¹⁰ The lowest and larger part is arenaceous with a thickness of about 3000 feet; the middle part consists of gritty slates and mudstones, with lenticular beds of limestone, and is about 1500 feet thick; the highest part consists entirely of fine shales with thin beds of nodular limestone, and is about 300 feet thick. The last has evidently been formed in much deeper water, for in this small thickness is comprised the whole of the Upper and part of the Middle Devonian.

Palæontologically, however, as many as seven subdivisions can be distinguished in the following descending order:—

Upper.	{	7. Shales of Rostellec. Black shales with nodular layers, <i>Tornoceras simplex</i> , <i>Bactrites</i> , <i>Entomis</i> , <i>Posidonomya venusta</i> , and <i>Buchiola retrostriata</i> .
		6. Shales of Traouliers. Green and brown, with <i>Rhynchonella cuboides</i> , <i>Rh. pugnus</i> , <i>Pentamerus globus</i> , and <i>Productus subaculeatus</i> .
Middle.	{	5. Slates of Porsguen. Greenish brown, with layers of calcareous nodules yielding many fossils of Middle Devonian species.
		4. Greywacke of Fret. Gritty calcareous slates with <i>Phacops Potieri</i> , <i>Spirifer paradoxus</i> , and <i>Sp. auriculatus</i> .
Lower.	{	3. Greywacke of Faou. Grits and slates with <i>Spirifer hystericus</i> and <i>Chonetes sarcinulata</i> , and limestone with <i>Athyris undata</i> .
		2. Sandstone of Gahard, white, with <i>Orthis Monnieri</i> and <i>Spirifer Pellicoi</i> about 300 feet thick.
		1. Plougastel Beds. Alternating beds of hard dark-green quartzitic grit, and rough greenish slates. Fossils rare, <i>Bellerophon trilobatus</i> , <i>Orthoceras planiseptatum</i> , <i>Pteria lavis</i> , <i>Spirifer octoplicatus</i> .

In this succession the Plougastel Beds appear to correspond with our Dartmouth slates and Glengarriff grits; the Gahard and Faou Beds correspond to our Meadfoot Beds and Staddon grits. The Middle Devonian Series is about 800 feet thick, but is very different from that of South Devon, both it and the Upper Devonian having a greater resemblance to the beds in Cornwall.

In the eastern basins of Laval and Angers another Devonian facies is found. Combining the work of M. Æhlert and the

correlations made by Professor Barrois the succession may be stated as follows :—¹¹

Upper	{	7. Shales with <i>Entomis</i> and <i>Posidonomya venusta</i> .
		6. Limestone of Fresnaie with <i>Bactrites</i> and <i>Tentaculites</i> .
Middle	{	5. Calcareous shales of Pont Maillet.
		4. Gritty slates with <i>Spirifer hystericus</i> and [<i>Dalmanites laciniatus</i>].
Lower	{	3. Limestones with <i>Athyris undata</i> .
		2. Sandstone with <i>Orthis Monnieri</i> .
		1. Quartzites and slates (Plougastel Beds).

Of these groups only 1 to 3 are found in the Laval Basin, and the lowest is much thinner than in the west. In the basin of Angers the Plougastel Beds are absent and the series begins with the equivalent of the Gahard sandstone ; the succeeding beds being all limestones or calcareous shales, and evidently deposited much farther from land than those of Western Brittany.

In the basin of Ancenis, still farther south, this change from an arenaceous to a calcareous facies seems still more marked, for the lowest beds there are limestones and shales of Middle Devonian age, but it is rather uncertain whether the absence of Lower Devonian is due to non-deposition or to faulting. There can be no doubt, however, that in passing from west to east we pass away from the land-area which supplied the arenaceous material, and this applies both to England and Brittany.

In Normandy only the Lower Devonian comes into the synclines, so that the facies of the Middle and Upper Devonian is unknown. The thickness is not great, for as in the south the Plougastel Beds are absent, and the lowest beds are hard sandstones with *Orthis Monnieri*, which represent the Grès de Gahard and rest unconformably on Silurian or Ordovician. Other fossils are rare. The sandstone is succeeded by slates with lenticular beds of limestone which contain *Athyris undata*, *Homalonotus Gervillei*, *Phacops Potieri*, *Spirifer Rousseaui*, and are clearly the equivalents of the greywacke of Faou and of the *Athyris undata* limestones of Anjou. The highest beds to be seen are brown mudstones with *Pleurodictyum*.

2. Spain

Devonian strata have been recognised in many parts of Spain, making it probable that nearly the whole of that country was covered by the Devonian Sea. Moreover, although the facies is to a large extent calcareous the fauna is similar to that of Northern France. As an example of the Spanish succession I select that of Asturia, which was described in detail by Professor C. Barrois in 1882 ;¹² this is as follows :—

Upper, 1000 feet	{ Red and grey marbles with <i>Goniatiles</i> . Unfossiliferous sandstones (500 feet). Limestone of Candas with <i>Spirifer Verneuilli</i> . Sandstones with <i>Gosseletia devonica</i> (150 feet).
Middle, 1000 feet	{ Limestones of Moniello with <i>Calceola sandalina</i> and <i>Cystiphyllum vesiculosum</i> . Limestones of Arnao with <i>Spirifer cultrijugatus</i> . Limestones of Ferrones with <i>Spirifer paradoxus</i> , <i>Rhynchonella Orbignyana</i> , and many corals.
Lower, about 1800 feet	{ Calcareous slates and limestones with <i>Spirifer hystericus</i> , <i>Rhynch. pila</i> , and <i>Homalonotus</i> . Furada grits, red and green grits with green and purple slates over 600 feet thick.

The lowest beds are comparable with the Plougastel grits and slates, and the overlying limestones are calcareous equivalents of the Gahard and Faou sandstones. The limestones of the Middle Devonian correspond with the beds which are known as Eifelien in the Ardennes, and it is curious to find the upper part of the series, which is usually calcareous, here represented by sandstones. In the Upper Devonian again there is a still thicker band of sandstones, proving that the deposition of limestone was temporarily interrupted by the invasion of a sand-bearing current, and that continental land was still not far away.

3. The Ardennes

In the Ardennes Devonian rocks occupy the greater part of an area lying partly in France and partly in Belgium, which is over 100 miles in length from west to east, and has a maximum width of about 50 miles (see map, Fig. 70). The area really consists of two basins, one broad and regular (basin of Dinant), the other deep, narrow, and isoclinal (basin of Namur), which are brought into apposition by a reverse fault (see Fig. 71). The throw or displacement of this fault amounts to many thousand feet, and the strata of the two basins must originally have been separated by an interval of several miles. That this was so is proved by the fact that while the southern basin, that of Dinant, contains a very thick representative of the whole Lower Devonian Series (average about 8000 feet), this is entirely absent in the basin of Namur.¹³

Lower Devonian.—On the south side of the basin of Dinant the Lower Series has a total thickness of about 10,000 feet. At the base, resting unconformably on Cambrian, is a conglomerate overlain by coarse felspathic sandstone or arkose; this is succeeded by a series of hard grits and slates, generally of green or red tints, but containing very few fossils. A fossiliferous band at Montrepuits

has yielded *Homalonotus Ræmeri*, *Spirifer Mercurii*, *Pterinaria ovalis*, and *Tentaculites*; elsewhere remains of *Pteraspis* have been found. This group of beds, of which the slates of St. Hubert are the highest member, are known as the *Gedinnian*.

The higher stage of the Lower Devonian is called the *Coblentzian*; this has 1500 feet of white sandstone (Grès d'Anor) at its base, followed by the greywacke of Montigny, the black sandstone of Vireux, the red slates of Vireux, and the Burnot conglomerate, the

Fig. 70.—MAP OF THE ARDENNES (drawn and lent by Professor J. Gosselet).
Scale about 35 miles to an inch.

whole being from 5000 to 6000 feet thick. The Anor sandstone has a special fauna, including *Spirifer primævus*, *Renssælleria crassica*, *R. strigiceps*, *Avicula lamellosa*, and *Kochia capuliformis*, and appears to represent a series of beds which are more fully developed near Coblentz, and are known as the Taunus quartzite. The grits and mudstones above this white sandstone are characterised by *Spirifer paradoxus*, *S. primævus*, *Rhynch. daleidensis*, and *Athyris undata*, while the higher beds contain *Spirifer paradoxus*, *Chonetes sarcinulata*, *Sp. hystericus*, and *Leptaena Murchisoni*.

The whole series becomes thinner toward the north, and along the northern side of the basin it is represented only by the variegated slates of St. Hubert and the Coblentzian Beds in a

rather different facies, the combined thickness being still, however, about 5000 feet.

Middle Devonian.—This also comprises two divisions, the *Eifelian* and the *Givétian*. In the former are now placed the Hierges Beds, flagstones and shales, which are subdivided into a lower zone of *Spirifer arduennensis* and an upper zone of *Sp. cultrijugatus*. In the basin of Dinant they are some 500 feet thick, and in the basin of Namur they are the lowest beds (with a basal conglomerate).

The next group is that of the Calceola shales; these are calcareous shales including lenticular beds of limestone which sometimes, as at Nismes and Couvin, swell out to a thickness of

Fig. 71.—SECTION THROUGH THE BASINS OF NAMUR AND DINANT (Gosselet).

H. Coal-measures.
C. Dinantian.

D. Upper and Middle Devonian.
R. Lower Devonian.

S. Cambrian and Orlovician.

300 to 500 feet, hence the group varies greatly in thickness, but has probably an average of 1000 feet. Its most characteristic fossils are the little coral *Calceola sandalina* with *Cystiphyllum vesiculosum*, *Mesophyllum helianthoides*, *Spirifer speciosus*, *Meristella plebeia*, *Phacops Schlotheimi*, and *Bronteus flabellifer*.

The *Givétian*, in its typical locality near Givet, is a mass of dark-grey limestone, over 1200 feet thick, and is specially characterised by certain Brachiopods, viz. *Stringocephalus Burtini*, *Uncites gryphus*, and *Spirifer mediotextus*, the bivalve *Megalodon cucullatus*, and the Cephalopods *Anarcestes cancellatus*, *Agoniatites inconstans*, and *Orthoceras dolatum*. The so-called coral reefs of the *Givétian* are merely thick lenticular masses of unstratified limestone formed by colonies of Stomatoporoids with *Favosites*, *Alveolites*, and other corals, such masses being generally surrounded by bedded crinoidal limestones or by calcareous shale and limestone.

Upper Devonian.—This is also divisible into two stages, the Frasnian and the Famennian. The former consists of shales and

Fig. 72.—SECTION FROM MEHAL HEAD TO KENMARE BAY.
Reduced from the Explanation of Sheets 192 and 199 of the Geological Survey of Ireland. Distance 3 miles.
G. Carboniferous shales and grits.
C. Glengariff grits and slates.

Fig. 73.—SECTION THROUGH THE SOUTHERN PART OF THE DINANT BASIN, ARDENNE (after Professor Gosselet).
Distance about 12 miles.

9. Limestone of Givet.
8. *Calceola* shales.
7. Greywacke of Hierges.
6. Red shales of Burnot.
5. Sandstone of Vireux.
4. Greywacke of Montigny.
3. Anor sandstone (Gres d'Anor).
2. Schists of Mondreputits, etc.
1. Arkose and conglomerate.
- A. Cambrian slates.

lenticular limestones, is about 900 feet thick near Givet, and is divisible into several zones, as follow :—

Shales of Matagne or zone of *Buchiola retrostriata*.
 Shales and limestones with many fossils.
 Zone of *Camarophoria* and *Rhynchonella pugnus*.
 Zone of *Spirifer orbelianus*.

In the northern part of the basin, near Frasné, the whole stage consists of limestone which is supposed to be 1600 feet thick. The species *Rhynchonella cuboides*, *Pentamerus brevirostris*, *Gephyroceras intumescens*, and *Geph. complanatum* range throughout.

The higher stage, Famennian, exhibits two distinct facies, the southern argillaceous and the northern arenaceous. The former has been divided into four zones, as follow :—

Etrœungt limestone with *Spirifer distans*.
 Shales with *Rhynch. ietiensis*.
 „ *Rhynch. Dumonti* } and *Iormoceras simplex*.
 „ *Rhynch. Omaliusi* }

Along the northern border it consists of shales and sandstones which have been divided as follows by Professor Gosselet :—

5. Shale and limestone (thin and possibly Carboniferous).
4. Sandstones of Dumont, soft brown and micaceous.
3. Calcareous shales of Choisis.
2. Flagstones of Cerfontaine.
1. Green shales of Colletet.

The upper sandstones contain *Cucullæa Hardingi*, *C. trapezium*, and *Palæopteris hibernica*. They resemble the Marwood Beds of North Devon.

4. Germany

The typical development of the Devonian in Germany is that of the Rhine valley and the neighbouring hill districts of the Eifel, the Hunsruch, and the Taunus. The region is actually connected with the Ardennes, and the succession is very similar, as will be seen from the following tabular description :—

Upper.	{ Nodular limestone and shale with <i>Clymenias</i> .	
	{ Shales with <i>Entomis</i> and <i>Posidonomya venusta</i> .	
Middle.	{ Calcareous shales of Budesheim with <i>Gephyroceras intumescens</i> .	
	{ Limestone with <i>Rhynch. cuboides</i> and <i>Camarophoria formosa</i> .	
	{ Giv.	{ Limestone with <i>Stringocephalus</i> (1200 feet).
		{ Crinoid limestones (30 feet).
	{ Eif.	{ Marly limestone with <i>Calceola</i> , <i>Spirifer speciosus</i> , <i>Phacops Schlottheimi</i> , etc.
		{ Shaly limestone with <i>Spirifer cultrijugatus</i> .

- Lower. { Coblentzian in three subdivisions—
 c. Slates with *Spirifer paradoxus* and *Phacops laciniatus*.
 b. Quartzites with *Spirifer auriculatus*.
 a. Greywacke with *Homalonotus ornatus*, etc.
 Hundruch Slates with *Phacops Ferdinandi*, *Homalonotus planus*,
 Dalmanites rhenanus, and *Spirifer primævus*.
 Taunus quartzite with *Spirifer primævus*, *Renssellaeria crassicosta*,
 and *Homalonotus Ræmeri*.
 Variegated sandstones and slates with arkose and conglomerate at
 the base.

In the Kellerwald district east of the Rhine and north of the Lahn the Middle Devonian consists mainly of shales with occasional bands of limestone, and this series has been subdivided by means of the *Goniatis* into the following zones :—

Gibétian	{	Zone of <i>Mæneceras terebratum</i> .
	„	<i>Tornoceras circumflexiferum</i> .
Eifelian	{	<i>Agoniatites occultus</i> .
	„	<i>Mimoceras gracile</i> .

The Harz Mountains also largely consist of Devonian rocks, but these have been the subject of much controversy, and it is only within the last fifteen years that the difficulties have been partially explained. The mountains form a range to the south of Brunswick between Gottingen and Halle, the central part or Brocken being a mass of intrusive granite rising to a height of 3700 feet. The Palæozoic area has a length of about 56 miles and a maximum breadth of 20, the western part being known as the Upper Harz and the eastern as the Lower Harz. Recent researches have shown that the whole area is much more plicated and dislocated than had been supposed,¹⁴ and that the supposed mixture of Silurian and Devonian faunas can to some extent be explained by these dislocations, for there is really a basal mass of Silurian age (see p. 185). The extent of this and the plane of division between it and the Devonian rocks have not yet been determined. The facts are these—below the Coblentzian quartzites there is a great thickness of slates and greywackes (the so-called Hercynian Series), and these contain few fossils except plant remains; but here and there are patches of limestone, and some of these are Devonian and consequently of Gedinian age. Thus the limestones of Scheerentweg and Klosterholz containing *Spirifer hercynicus*, *Sp. Decheni*, and *Rhynch. princeps* and that of Herzgerode containing the peculiar Gastropod *Hercynella* (allied to recent *Siphonaria*) are referable to the Devonian.

The Coblentzian is represented by a set of quartzites without fossils which pass up into fossiliferous sandstones containing many

species of *Spirifer* (*S. macropterus*, *S. cultrijugatus*, etc.) with *Chonetes sarcinulata*, *Homalonotus gigas*, and *Ctenocrinus*.

The Middle Devonian of the Upper Harz is largely argillaceous, consisting in the lower part of interbedded shales and argillaceous limestones with *Calceola sandalina* and other fossils. Above these are sheets of diabase and a thin band of *Stringocephalus* limestone succeeded by the Goslar shales which, however, seem to be partly of Upper Devonian age. In the Lower Harz the Givétian is better represented by the limestone of Elbingerode with its associated beds of ironstone and volcanic tuff; this limestone has yielded the *Goniatites Meneceras terebratum* and *Tornoceras cinctum*.

The Upper Devonian as developed in the Western Harz comprises the following beds :—

- "Cyrpidina shales" with *Eutomis serrato-striata*.
- Green limestone with *Clymenias* and *Phacops brevis*.
- Black limestone of Altenau with *Goniatites retrorsus*.
- Shales with thin layers of black chert.

Near Clausthal, however, two hills called the Iberg and the Winterberg are of much interest, for they are parts of an isolated mass of Upper Devonian limestone, rising through the surrounding Carboniferous shales and greywackes, which are folded and crumpled round its sides. This Iberg limestone is believed to be 1300 feet thick, and has more resemblance to a coral reef than any such limestone mass in England or France. It is a massive limestone composed mainly of the remains of corals and shells, including several species of *Acervularia*, the Brachiopods *Rhynch. cuboides*, *R. pugnus*, *Orthis striatula*, and *Spirifer bifidus*, and the Cephalopods *Gephyroceras intumescens* and *G. Wurmii*, with many species of Gastropoda.

Devonian rocks crop out again to the south in Thuringia, but are much broken and flexured, so that there is no continuous succession.

5. Bohemia

The Silurian Series recorded on p. 184 is succeeded by limestones which must be referred to the Devonian System, in spite of their containing a mixture of Silurian and Devonian fossils which caused them to be regarded for many years as a part of the Silurian. These beds form the stages F₂, G, and H of Barrande (see Fig. 45, p. 143), and exhibit the following descending succession :—

	Feet.
H ₂ and ₃ . Grey shales of Hostin with carbonaceous layers	850
H ₁ . Grey shales, containing species of <i>Orthoceras</i> , <i>Gyroceras</i> , and <i>Goniatites</i>	
G g3. Nodular limestone with many Cephalopoda	1000
G g2. Calcareous shales with trilobites and brachiopoda	
G g1. Nodular limestone with a large fauna	
F 2. { Red crinoidal limestone of Menan } about 100	
{ White limestone of Konjprus }	
	1950

Of this series only the lower two members are referable to the Lower Devonian, of which they must be regarded as a concentrated calcareous facies formed in fairly deep water and under condition very different from those which prevailed in regions farther north and west. The red and white limestones are really different facies of one mass of limestone, the one often replacing or becoming interbedded with the other.

The interrelation and correlation of these limestones has been the subject of a recent study by F. Seeman,¹⁵ who calls them the zone of *Aphyllites fidelis*, this species of *Goniatite*, together with *Mimoceras gracile* and *Anarcestes crispus*, being common.

The whole of Stage G belongs to the Middle Devonian, and though near Prague there is a central band of shales, near Beraun to the south-west it is, according to Seemann, entirely composed of limestone, the lower beds being characterised by *Anarcestes subnautilinus* and the upper by *An. occultus*. Other common fossils are :—

Bronteus Brongniarti.
Phacops fecundus.
Cheirurus Sternbergi.
Goniatites fecundus.
Orthoceras annulatum.

Gomphoceras biconicum.
Hercoceras mirum.
Pteria grandis.
Chonetes novellus.
Coccosteus Agassizi.

Seemann also refers H¹, in which *Posidonomya hians* is the most characteristic fossil, to the Middle Devonian, regarding the rest of H as representative of the Upper Series.

6. Poland and Russia

North of Bohemia in Russian Poland, near Lagow and Kielce, there is an interesting conjunction of an arenaceous littoral and a calcareous marine facies. There the lowest Devonian Beds are sandstones with Placoderm fish (*Coccosteus*, *Heterosteus*, etc.), associated with other beds containing *Spirifer paradoxus*. These beds must be referred to the highest Coblenzian or lowest Eifelian,

and there is nothing analogous to the Gedinian fish fauna of *Pteraspis* and *Cephalaspis*, etc.; consequently it is supposed that the Lower Devonian has thinned out northwards from Bohemia and eastwards from the Harz district against the shore of a northern Devonian continent; for though the Devonian is largely developed in the Baltic provinces of Russia, it does not include any representative of the Lower Series.

Both Middle and Upper Devonian are well developed in Poland; the former by a series of marls and limestones with *Calceola sandalina* and many of the typical Eifelian and Givetian fossils, the latter by limestone and shales in the following order:—

3. Clymenia shales in three zones.
2. Calcareous shales with *Geph. intumescens*.
1. Kielce limestone with *Rhynch. cuboides*.

In the Baltic provinces (Livonia and Courland) a red sandstone with fish remains lies unconformably on both Silurian and Ordovician, and is succeeded by dolomitic limestones with a marine fauna. These limestones are divisible into four bands, the two lower containing a local fauna of *Spirifers* and other Brachiopods; the third band, however, yields many characteristic Givetian species, so that the lower are doubtless equivalent to the Eifelian, and the highest bed is marked by the abundance of another species of *Spirifer* (*S. Anosoffi*).

Finally, there is a second set of sandstones taking the place of the Upper Devonian, and comparable to the British Upper Old Red Sandstone, for they contain *Holoptychius* and *Asterolepis*. Eastward, however, in Central Russia they are replaced by red marls and limestones with marine shells, and still farther east, on the flanks of the Ural Mountains, we again find a complete marine facies of the whole Devonian System. Apparently Novaya Zembla was also covered by the Devonian Sea, for at Cape Grebein vertical beds with *Proetus* are regarded as Lower Devonian, and are conformably succeeded by strata which have yielded *Spirifer Anosoffi*.

II. THE OLD RED SANDSTONE FACIES

As stated on p. 199 the marine Devonian facies does not occur in Britain north of the Bristol Channel, its place in Wales, Scotland, and the north of Ireland being taken by the great series of sandstones, marls, flagstones, and conglomerates, which are still known by the cumbrous name of the Old Red Sandstone.

Although this Old Red Sandstone is believed to be divisible into

three series, a Lower, Middle, and Upper, which may be homotaxial with the Lower, Middle, and Upper Devonian, yet it is not certain

Fig. 74.—FOSSILS FROM THE OLD RED SANDSTONE.

a. <i>Estheria membranacea</i> .	c. <i>Pterichthys Milleri</i> .
b. <i>Coccosteus decipiens</i> .	d. <i>Pterygotus anglicus</i> .
e. <i>Cephalaspis Lyelli</i> .	

that all three divisions are found together in one area, and it is certain that in most parts of the country only two such series exist, the Upper being unconformable to the Lower.

A. FLORA AND FAUNA

The fauna of the Old Red Sandstone is not a large one, but in certain localities remains of fish and Eurypterids occur in some abundance; plants also occur, but the only Mollusc yet found is the *Archanodon Jukesi* of the Upper Old Red, and this more closely

Fig. 75.—FOSSILS OF THE UPPER OLD RED SANDSTONE.

a. *Holoptychius nobilissimus*.

b. *Phaneropleuron Andersoni*.

c. *Archanodon Jukesi*.

resembles a fresh-water mussel than any marine form. From this limited fauna, and the total absence of any unquestionably marine species, it has been supposed that the Old Red Sandstones were lacustrine deposits, and that the greater part of Northern Europe was at this time a continent, within which lay several large lake-areas comparable to those of North America at the present day.

The plants of the Old Red Sandstone are the ancestors of the

Carboniferous flora, and are chiefly lycopods and ferns. The former include *Lepidodendron*, *Sagenaria*, *Knorria*, *Stigmara*, and *Psilophyton*; ferns are presented by *Palæopteris*, *Neuropteris*, and *Sphenopteris*; *Calamites* occur, and coniferous wood is also not uncommon.

Fish are the most conspicuous and abundant members of the fauna, and several orders are represented: the Ostracoderms by *Cephalaspis*, *Pteraspis*, *Scaphaspis*, and *Holaspis*; the Dipnoids by *Coccosteus*, *Phaneropleuron*, *Dipterus*, and *Homosteus*; the Elasmobranchs by *Acanthodes*, *Cheiracanthus*, *Diplacanthus*; the Crossopterygians by many genera, such as *Osteolepis*, *Glyptolepis*, *Gyroptychius*, *Diplopterus*, and (in the upper division) *Holoptychius*. The remains of fish are very abundant at certain horizons in Scotland, but they are not generally distributed through the mass of the formation.

The Merostomata are represented by *Pterygotus*, *Eurypterus*, *Styloneurus*, and the only other organic remains found in British strata are the Phyllopod *Estheria*, two Myriapods, and a Lamellibranch (*Archæanodon*). In Canada, however, insects of several kinds have been found in rocks of corresponding age and character. The following are some of the more characteristic Old Red Sandstone fossils:—

Fossils of the Lower Division

<i>Plants.</i>	<i>Psilophyton robustum</i> , <i>Parka decipiens</i> .
<i>Myriapoda.</i>	<i>Archidesmus Macnoli</i> , <i>Kampecaris forfarenensis</i> .
<i>Merostomata.</i>	<i>Pterygotus anglicus</i> , <i>Eurypterus pygmæus</i> , <i>Stylonurus Symondsii</i> .
<i>Pisces.</i>	<i>Cephalaspis Lyelli</i> , <i>Pteraspis rostrata</i> , <i>Pterichthys cornutus</i> , <i>Pt. Milleri</i> , <i>Mesacanthus Mitchelli</i> , <i>Diplacanthus gracilis</i> , <i>Climatius scutiger</i> , <i>Parexus incurvus</i> .

Fossils of the Middle Division

<i>Plants.</i>	<i>Lepidodendron gaspæanum</i> , <i>Calamites transitionis</i> .
<i>Crustacea.</i>	<i>Estheria membranacea</i> .
<i>Pisces.</i>	<i>Coccosteus decipiens</i> , <i>C. minor</i> , <i>Thursius pholidotus</i> , <i>Th. macrolepidotus</i> , <i>Homosteus Milleri</i> , <i>Glyptolepis paucidens</i> , <i>Dipterus macropterus</i> , <i>Osteolepis microlepidotus</i> .

Fossils of the Upper Division

<i>Plants.</i>	<i>Palæopteris hibernica</i> , <i>P. Browni</i> , <i>Cyclopteris Kiltorkense</i> , <i>Stigmara ficioides</i> , <i>Knorria Baillyana</i> , <i>Sphenopteris flaccida</i> .
<i>Mollusca.</i>	<i>Archæanodon Jukesii</i> .
<i>Pisces.</i>	<i>Holoptychius nobilissimus</i> , <i>Bothriolepis major</i> , <i>Glyptopomus minor</i> , <i>Phaneropleuron Andersoni</i> , <i>Asterolepis maxima</i> , and <i>Psammosteus Taylora</i> .

B. STRATIGRAPHY OF THE OLD RED SANDSTONE

1. *Wales and the Welsh Borders*

In Monmouth, Hereford, and Brecknock a great thickness of red sandstones and marls intervenes between the Silurian and the Carboniferous, and from these counties extensions of Old Red Sandstone stretch westward through Carmarthen and South Pembroke, northward into Radnor and Shropshire, and eastward into Worcester and Gloucester. It is evident, therefore, that in all these directions the formation originally extended considerably beyond its present limits. According to recent estimates, its maximum thickness in Brecknock may be 7000 feet, but from this central area it thins in every direction, being only 4200 feet at Abergavenny in Monmouth, and 3500 at Newport; while northward in Shropshire its thickness is believed to be 3700.

The area over which the sandstones and marls of this system still extend measures over 100 miles from west to east, and about 80 miles from Cardiff in the south to beyond Bridgenorth in Shropshire. The system is naturally divisible into three parts or series, which were long ago recognised by W. S. Symonds, under the names of (1) Lower or Cornstone Series, (2) Middle or Brownstone Series, (3) Upper Old Red. These divisions have been adopted by the Geological Survey in their recent revision of South Wales, but there remains much doubt whether the Brownstone Series represents any part of the true Middle Old Red. In the eastern parts of the area the whole seems to form a conformable succession, but when followed westward into Carmarthen the Brownstones thin out near Kidwelly, and the conglomerate of the Upper Group overlaps on to the lower series. They recur in Gower to the south, but are only 100 feet thick, and seem to belong rather to the Upper Old Red than to be an independent group. Hence the arrangement of the Geological Survey is as follows:—

Upper Series	{	Yellow and red sandstones, grey grits, and quartz-pebble conglomerates.
		Brownstones. Red and brown sandstones, with occasional beds of marl and cornstone.
Lower or Cornstone Series	{	Green and dull-red sandstones with some beds of marl, cornstone, and conglomerate.
		Red marls with beds of nodular limestone (cornstone) and occasional beds of micaceous sandstone.

Cornstone Series.—In Brecknock and the east of Carmarthen this red marl and cornstone series has a great thickness, possibly as much as 4500 feet. The greater part of it consists of hard red

sandy marls with layers of hard calcareous nodules which sometimes coalesce so as to form beds of compact red or green limestone; while in other cases the embedding marl seems to have been washed away by contemporaneous erosion, leaving the nodules to form a "cornstone conglomerate." The nodules themselves consist of amorphous carbonate of lime, and nothing but obscure traces of plants have been found in them. They have probably been formed by the agency of lime-secreting algæ.

The Senni Beds only occur along the northern outcrop, and gradually thin out westward, disappearing a little before the Brownstones. Their maximum thickness is 1200 feet, and they have been included in the lower series because the remains of *Pteraspis* have been found in them. Both *Pteraspis* and *Cephalaspis* have been found in the Red Marls, and consequently it may be inferred that this Lower Old Red is the equivalent of the Lower Devonian and that there was some water communication, by river or inlet, between the two areas of deposition.

During the resurvey of the Gower district, in the south-west corner of Glamorgan, it was discovered that the underlying Silurian rocks rose to the surface within the Old Red Sandstone area and formed two small inlying tracts; further that the Cornstone Series, though present, thinned out within the area against the slope of the Silurian rocks. Thus some 300 feet of red marls are visible below Rhossili Down, and are overlain by Brownstones which are succeeded, without any sign of unconformity, by 300 feet of quartz-pebble conglomerates (see Fig. 77). On Cefn-y-Bryn, however, the red marls are absent, and Brownstones (only 100 feet thick) rest on the Silurian and are covered as before by the conglomerates.¹⁶

Still farther west, however, in Pembrokeshire the Red Marl Series regains its normal thickness, being over 3000 feet along its southern outcrop and nearly as much on the northern side. If, therefore, the Gower ridge was continued westward it must have passed some distance to the south of Milford Haven.

Upper Old Red Series.—The Brownstone Group consists mainly of sandstone, bright red or reddish brown, with subordinate beds of marl and occasional cornstones. In the area round Brecknock, where they form the lower slopes of the Brecon Vans and the Black Mountains (see Fig. 76), it may have a thickness of about 2000 feet, but this decreases in all directions. As already stated, they thin out entirely to the westward and do not occur in Pembrokeshire. No fossils of any kind have been found in them.

The highest group of beds is never more than 500 feet thick; it commences with a conglomerate composed in most places of

- 8. Carboniferous rocks.
- 7. Upper Old Red Sandstone.
- 6. Brownstone Series.
- 5. Red marls and sandstones.
- 4. Red marls and cornstones.
- 3. White sandstones.
- 2. Red marls and flagstones.
- 1. Ludlow Beds.

- f. Upper Black Shales.
- e. Avonian Limestones.
- d. Lower Shales.
- c. Upper Old Red.
- b. Brownstones.
- a. Silurian rocks.
- m. Alluvium.
- FF. Faults.

pebbles of vein-quartz which are so water-worn and rounded that they resemble the pebbles of a shingle-beach. In the northern and eastern part the shingle is succeeded by beds of sandstone, marl, and shale which pass up into the Carboniferous Series, and these beds have in several places yielded remains of fish and plants. The fish belong to the genera *Bothriolepis*, *Holoptychius*, and *Sauripterus*, and shells of *Archæonodon Jukesi* have also been found.

In the extreme south and south-west these uppermost beds have a different aspect. Thus in Gower the conglomerate is no less than 300 feet thick and contains, besides the usual quartz pebbles, some of quartzite, together with angular pieces of red jasper, many of which appear to be pieces of silicified rhyolite or other igneous rock. Again in Pembrokeshire, along the northern outcrop and near Tenby, the group consists of quartzitic grits passing up into sandstones, marls, and shales; and at West Angle Bay, south of Milford Haven, two bands of marine fossiliferous beds occur in this sandstone group. The lower band commences about 125 feet below the line taken for the top of the group, and consists of grey shales and sandstones with thin bands of limestone; the second is some 50 or 60 feet higher. Both these bands contain marine shells, chiefly Lamellibranchs such as *Ptychopteria damnoniensis*, *Cucullæa trapezium*, *Curtonotus elegans*, with *Rhynchonella laticosta* and other characteristic fossils of the Marwood and Pilton Beds in North Devon. Here, therefore, as pointed out by Dr. Strahan, we have evidence of temporary incursions of the sea into an area which had previously lain within the borders of continental land, and was presumably part of a large lake-basin.

2. Scotland

In Scotland there are four principal areas where the Old Red Sandstones are found, and in some of them they attain a much greater thickness than in England. These areas are: (1) parts of Berwick, Roxburgh, and of Northumberland, including the Cheviot Hills; (2) the area of the central lowlands, underlying the Carboniferous rocks and coming to the surface both on the southern and the northern side of the great basin; (3) a smaller tract in Argyleshire between the Firth of Lorne and Loch Awe; (4) a large irregular tract in the north-east, bordering the Moray and Cromarty Firths and stretching northward through the east of Sutherland to Caithness and the Orkney Islands.

It has been imagined that these four areas were distinct and separate basins of deposition, at any rate during the earlier part of the period; that they were disconnected from the sea and formed large inland lakes. Sir Archibald Geikie has indeed proposed

separate names for these lakes, calling the first Lake Cheviot, the second Lake Caledonia, the third Lake Lorne, and the fourth Lake Orcadie. This view, however, is not sufficiently supported by the facts, so far as the three southern areas are concerned; the Lorne and Cheviot areas were probably only extensions or bays connected with one large Caledonian lake basin, which may also have stretched south-westward into the north of Ireland, for patches of Old Red occur at the very southern end of the Kintyre promontory. The northern area, on the other hand, exhibits a different set of beds which contain a different fish fauna, so that there does seem to have been a Lake Orcadie or at any rate a separate Orcadian basin of deposition.

In the central area the Lower Old Red Series is of great thickness, but no middle division exists, and the Lower Series is overlain unconformably by the Upper Old Red, which passes conformably into the overlying Carboniferous Series. In the Orcadian area there is nothing which can be identified as Lower Old Red, but there is a great thickness of the Middle Series with an abundant fish fauna, and some patches of Upper Old Red resting unconformably upon the beds below.

There is a further great difference between the rocks of the two areas. In all the southern districts the sandstones are interstratified with thick sheets of andesitic lava and beds of volcanic tuff and agglomerate, giving proof of volcanic action on a very large scale, and from many volcanic vents, throughout the whole of the Lower Devonian epoch. In the Orcadian area, on the contrary, no such volcanic rocks are found, so that the eruptions do not seem to have continued into the time of the Middle Series.

In the following account of the stratigraphic succession of beds these volcanic materials will only be mentioned incidentally, and for more information about them the student is referred to Sir A. Geikie's *Ancient Volcanoes of Great Britain* (1897).

Caledonian Region.—The Lower Old Red Sandstone is most completely developed on the northern side of the great central or Lowland trough, and the beds are finely exposed in the cliffs of the Kincardine and Forfar coasts. Until quite recently this series was supposed to include all the red rocks visible in Kincardine, but as stated on p. 163 the lowest set of beds must now be regarded as the highest part of the Silurian System.

The base of the Old Red Sandstone is the massive conglomerate which forms Downie Point near Stonehaven, and this is part of a group of coarse sandstones and conglomerates to which Mr. G. Hickling¹⁷ has given the name of Dunottar Conglomerate (see Fig. 78). These beds occupy a long stretch of coast-line which

is here nearly parallel to the strike. Mr. Hickling estimated their thickness to be 5000 feet, and the comparative narrowness of their outcrop is due to their high inclination. The conglomerates of this group consist partly of quartzite pebbles, derived from the quartzites of the Highlands, and partly of angular and subangular fragments of jasper, chert, and "green-rock" derived from the "Margie Series" (see p. 97), showing this series must then have had a considerable northward extension over the Highland region.

The Dunottar Group is succeeded by the Sidlaw Group, which includes the contemporaneous lavas of the Sidlaw Hills and the overlying grey sandstones and flagstones (? 500 feet), which are followed by beds of coarser grain (the Cairnconnon Group), and perhaps 2000 feet thick. The fourth group is the Red Head Series, which consists of red sandstones with bands of hard red shale, and locally some bluish-grey shales. These beds are overlain by the Auchmithie conglomerate from 500 to 800 feet thick, and mainly composed of large rounded pebbles of quartzite. No fossils have yet been found in any of the beds above enumerated, except a few in the Red Head Series.

The succeeding Arbroath sandstones comprise coarse gritty sandstones and some flagstones, both of red and grey colours, with a single bed of marly limestone at Arbroath, probably on the same horizon as a limestone which has been mapped inland to the westward. Fossils have been found at four horizons in these beds, and include *Cephalaspis Lyelli*, *Pterygotus anglicus*, *Kampecaris forfarensis*, and the plant *Parka decipiens*.

The highest beds of the whole series (the Edzell shales) are not exposed on the coast, but only occur in the deeper parts of the synclinal trough of Strathmore (see Fig. 78). The following is a tabular résumé of the succession and thicknesses:—

	Feet.
Edzell shales	1,000
Arbroath sandstones	1,200
Auchmithie conglomerate	800
Red Head Series	1,500
Cairnconnon Group	2,000
Carmyllie or Sidlaw Group	1,000
Dunottar conglomerate	5,000
	<hr/>
	12,500

[I am indebted to Mr. Hickling for the drawing of the section across Forfar, from which Fig. 78 has been made.]

The great series of sandstones, conglomerates, and volcanic rocks above described forms a continuous band across Scotland from the coasts of Kincardine and Forfar to that of Dumbarton on

Fig. 78.—SECTION ACROSS FORFAR FROM THE HIGHLAND BORDER TO NEAR ARBROATH. (Distance 20 miles.)

10. Upper Old Red.
9. Edzell shales.
8. Arbroath sandstone.
7. Auchmithie conglomerate.
- 5, 6. Red Head Group.
4. Cairncommon Beds.
3. Carnyllie Beds.
2. Dunottar conglomerate.
7. Stonehaven Beds (Silurian).
6. Margie sandstones.
- a. Green rocks.
- x. Highland schists.

Fig. 79.—SECTION FROM BARWICK BURN NEAR CRIEFF TO KINROSS. (Distance 23 miles.)

- C4 Upper Old Red.
- C2 Lavas and tuffs.
- C1 Lower Red Sandstones.
- A. Highland schists.
- FF. Faults.

the Firth of Clyde, a distance of about 120 miles. For the greater part of its extent the breadth of outcrop is about 20 miles, but it narrows in Dumbarton where the thickness is probably less.

On the north-west side it is cut off by the great boundary fault; but in Perthshire and the west of Forfar this is not a single but a double line of fault, and there are small tracts of the Old Red rocks beyond the second fault-line, resting on the schists and quartzites of the Highland complex (see Fig. 79). These outliers prove that the formation had originally a considerable extension to the northward over the rocks of the Central Highlands. If, indeed, the thickness of the series in Perthshire was as great as it is on the eastern coast, the height of the mountains which then formed the Highland range must have been well over 12,000 feet, and it is clear that the present hills are but the denuded stumps of a Devonian Alpine Range.

Further, since the lower slopes of this range seem to have been gradually buried beneath the increasing pile of red sandstones and lava-flows, it is not surprising to find a large tract of volcanic rocks in Lorne associated with sediments which prove the whole to be of Lower Old Red age. These rocks form the plateau of Lorne, which consists of a succession of terraces and escarpments, rising to 1700 feet above the sea and composed of felsitic and andesitic lavas with occasional layers of agglomerate, conglomerate, and red shale. At the base, and exposed along the coast near Oban and in Kerrera Island, are shales and flagstones with a boulder conglomerate at the base from 20 to 200 feet thick. These beds have yielded remains of *Cephalaspis*, *Pterygotus*, *Kampecaris*, and the plant *Psilophyton*. Still farther north in Glencoe is another patch of andesites with some shales in which *Psilophyton* and *Pachytheca* have been found.

On the southern side of the great Lowland syncline the Lower Old Red crops out in a more irregular manner, and is only exposed in disconnected areas in Ayrshire, Lanark, and the Pentland Hills. The beds described on p. 177 as forming the highest member of the Silurian System were formerly classed with the Old Red Sandstone, but the base of the latter is now taken at a band of conglomerate containing greywacke pebbles which is recognisable in all three districts. Near Lesmahagow (Lanark) this conglomerate rests with apparent conformity on the red Silurians, and is succeeded by chocolate-coloured sandstone containing *Cephalaspis Lyelli*, but in Ayrshire and in the Pentlands the basal conglomerate is markedly unconformable to this Silurian Series.¹⁸ Fig. 59 is a diagram section showing the general relations of these beds in the Pentland district.

Just as the northern belt is cut off by the Highland boundary fault, so the southern tracts are cut off by the boundary fault of the Southern Uplands, which runs from the coast near Ballantrae north-eastwards till it passes beneath the Carboniferous basin of Dalkeith. A small tract of Lower Old Red near Eyemouth in Berwickshire shows that the Caledonian area of deposition was prolonged southward, and there can be little doubt that the Cheviot area was also a part of it. The Cheviot Hills consist mainly of massive andesitic lava-flows with intercalations of tuff and ashy sandstone, and there are some beds of sandstone and conglomerate at the base, but of no great thickness.

Passing now to the Upper Old Red Sandstone of the Caledonian region we find this everywhere marked off from the Lower Series by a great break and unconformity. It occurs only in isolated tracts, and frequently oversteps the limits of the Lower Series on to the older rocks. The interval of time which elapsed between the two epochs of deposition must have been a long one, for Mr. Hickling finds that in Forfar no less than 8000 feet of material had been removed from the main anticline before the Upper Old Red was deposited; in other words, the Lower Series was flexured and then denuded to that extent in the interval which is elsewhere partially filled by the Middle Old Red.

The Upper Series occupies several more or less extensive tracts in different parts of the region, the largest being that in the south-east, Roxburgh and Berwick, where it extends from the northern borders of the Cheviots by Jedburgh and Earlston to Lauder and Greenlaw, and then all round the Lammermuir Hills to the coast at Dunbar. A smaller tract is found in the Pentland Hills, and others in Lanark and Ayrshire. On the northern side of the Lowland area two long belts of it lie between the boundary of the Lower Series and the outcrop of the Carboniferous sandstones, the one extending from the Clyde to the Forth near Stirling, the other from Kinross and Loch Leven to Cupar and Leuchars in Fife. There are also some small tracts in Forfar.

The following description of the beds composing this Upper Old Red is condensed from the account given by the late J. G. Goodchild, and is applicable to all the more eastern tracts.

The series is divisible into a lower and upper stage; the lower consists of a variable set of conglomerates and sandstones, the coarser beds being at and near the base, and the sandstones becoming finer in grain and more interstratified with marls towards the top; the sandstones also become more and more largely composed of rounded wind-worn grains. The prevalent colour is bright red; the thickness is variable (from 100 to 500

feet), and fossils are scarce, but scales of *Holoptychius* occur. The upper or Cornstone Group consists of sandstones and flagstones of pale red or yellow colours with marls and layers of the hard calcareous nodules which are known as cornstones. Fish remains are abundant in places, especially at Dura Den, near Cupar, where most of those mentioned on p. 226 have been obtained. This upper group is just as clearly a lacustrine deposit as the lower part of the series is one of accumulation in dry and wind-swept desert plains. The total thickness in Fifeshire is about 1000 feet.

Orcadian Region.—The present visible extent of the Old Red Sandstone has been mentioned on p. 230, but it must have a much greater extension under the bed of the North Sea both in eastern and northern directions, for the general dip of the beds is to the north-east, and their estimated thickness is 16,000 feet.

The whole of this thickness is ascribed to the Middle Old Red Series because of the peculiar fish fauna which it contains. It is divisible into four fairly distinct groups:¹⁹ (1) the lowest consists of red conglomerates, sandstones, and mudstones resting on and against the Archæan rocks and largely developed near Berriedale, from which place its outcrop runs N.N.W. to Sandside Bay, west of Thurso; (2) the Lybster Beds or lower flagstone group—dark-blue flags and shales, with occasional beds of sandstone and of black, often bituminous, limestone; (3) the Thurso Beds or upper flagstones, which are of pale grey or green colours and include but few limestones; (4) the John o' Groats sandstones of red and yellow tints. In tabular form the succession and thicknesses are :—

	Feet.
John o' Groats sandstones . . .	about 2,000
Thurso Flagstone Group . . .	„ 7,000
Lybster Flagstone Group . . .	„ 5,000
Berriedale Beds . . .	„ 2,000

About 16,000

Fish remains are most abundant in the Flagstone Beds, the lower group yielding *Thursius macrolepidotus*, *Dipterus macropterus*, and *Osteolepis*; the higher beds contain abundant remains of *Cocosteus* (*C. decipiens* and *C. minor*) with many others (see p. 226). The highest group has yielded plant remains, such as *Lepidodendron gaspeanum*, *Paleopteris Browni*, and *Calamites transitionis*, which occur also in the Devonian of Canada.

A fish bed of special importance occurs at Achanarras, some 10,000 feet above the base of the formation, while a similar assemblage of species has been found in the Moray area not very far above the base, and if the two beds are really on the same

stratigraphical horizon a thickness of about 9000 feet must have thinned out southwards and have been overlapped by the beds containing the Achanarras fauna. Such an overlap had been inferred on other grounds by Sir A. Geikie many years ago, and on this view it is only the highest part of the Middle Old Red Series which occurs in Nairn and Inverness and in the outliers which are found in Aberdeen.

This northern basin includes also some tracts of Upper Old Red, which rests with a marked unconformity on the Middle Series. From 600 to 800 feet of red and yellow sandstones can be seen. They occupy a tract of some length in Moray and Nairn, and outlying patches occur at Tarbat Ness, round Dornoch, at John o' Groats and Dunnet Head, and again in the Island of Hoy.

3. *The North of Ireland*

As already mentioned, several tracts of Lower Old Red occur in the north of Ireland, and others may be concealed beneath the newer strata. One such tract occupies an area about 30 miles long by 10 wide, between Lough Erne and Pomeroy in Tyrone. "It consists for the most part of dark-red and purple conglomerates, often coarse and massive, and of purple pebbly and fine-grained sandstones, . . . with sandy shales. The pebbles in the conglomerate, which vary from the smallest size up to blocks over a foot in diameter, consist of purple felstone, grits, schists, and quartzite. Of all these the felstone pebbles are by far in greatest proportion," and have been derived from the breaking up of contemporaneous lava streams, some sheets of which still remain interbedded with the conglomerates.²⁰

The second area is on the east coast of Antrim between Cushendall and Cushendun. Here again are conglomerates at the base, consisting mainly of quartz pebbles; above these is a series of red and brown sandstones succeeded by a breccia composed of large blocks of quartz-porphry; the whole is estimated to be 5000 feet thick. This tract forms a link between the Tyrone area and the Lower Old Red of the Kintyre promontory.

Another tract of similar material has been found in Donegal between Lough Swilly and Mulroy Bay. This consists of a basal conglomerate succeeded by chocolate-coloured sandstones and shales with some pebbly beds, and the materials are all derived from the surrounding quartzites and schists. The thickness seen is about 800 feet. Nothing corresponding to the Upper Series has been found in the north of Ireland, though it undoubtedly occurs in the southern part of the country (see p. 211).

4. *Norway*

Some small tracts of red sandstone and conglomerate occur on the west coast of Norway between the Sogne and the Ludvig fiords (see map, Fig. 10). They rest unconformably on Silurian and older rocks, but the maximum thickness is not more than 1200 feet. It is very probable that they belong to the western border of the Orcadian basin of deposition, in which case they are likely to be Middle Old Red Sandstone; but no fossils have yet been found in them to confirm this assumption.

5. *Arctic Regions*

Sandstones of the Old Red facies have also been found in several parts of the Arctic regions, notably in Spitzbergen, Bear Island, and Greenland.

In Spitzbergen, both Lower and Upper Old Red Sandstones occur. The lower beds, exposed in Dickson's Bay, consist of red and green sandstones, and have yielded species of *Pteraspis*, *Cephalaspis*, and *Acanthaspis*. The Upper Old Red has been explored at two localities, the Muner Valley and Grey Hook Point. At the former the beds consist of red and green sandstones with a band of grey shale enclosing ironstone nodules, in which fish of the genera *Psammosteus*, *Asteroplex*, *Onychodus*, and *Holoptychius* occur, together with plant remains (*Lepidodendron* and *Bothrodendron* (= *Cyclostigma*). At the other place (Grey Hook Point) there is a series of black shales and hard grey sandstones, and these have yielded a number of curious Mollusca which appear to be fresh or brackish-water forms; for no essentially marine genera occur, and they are all bivalves which have been referred by Dr. Kayser to the following genera, *Archanodon*, *Palæomutela*, *Myalina*, *Pteria* (?), and *Nathorstella*.²¹

The relations of the Upper Series to the Lower have not yet been ascertained, nor the thickness of either, for the whole mass occupies a deep faulted trough which crosses the island from north to south, so that the base is not seen; but de Geer has estimated the parts exposed to be over 4000 feet thick.

Bear Island lies to the south of Spitzbergen, and the greater part of it consists of beds which belong to the Upper Old Red Series.²² There is a basal conglomerate resting unconformably on Ordovician limestones and succeeded by a series of sandstones with bands of carbonaceous shale and seams of coal; these beds have yielded many interesting plants, including species of *Archæopteris*, *Sphenopteris* (*Sphenopteridium*), *Cephalopteris*, *Pseudobornia ursina*,

Bothrodendron kiltorkense, and four other species with *Stigmaria ficoides* and others. There are also remains of the fish *Holoptychius giganteus* and *H. monilifer*.

Again Upper Old Red has been found on the east coast of Greenland, the beds being red and brown sandstones from which fish of the genera *Holoptychius* and *Asterolepis* have been obtained.

From these facts it is clear that the Old Red Sandstone facies has a very large extension in the Arctic regions, and that the continent within which these deposits were formed reached from England to Spitzbergen, and from Greenland at least as far as Sweden, and probably through Northern Russia where sands and marls with fish remains occur near Archangel, without any marine deposits, but marine Devonian strata do occur in Novaya Zembla.

C. GEOGRAPHY AND HISTORY OF THE PERIOD

The general geographic conditions under which both the marine Devonian and the Old Red Sandstones were deposited have been fairly well indicated in the preceding pages, and the student will doubtless have realised that the greater part of Northern Europe, together with the whole of the North Sea area and part of the Atlantic Region, formed at this period a large continental tract of land. By some authors the Devonian has been called "the first continental period," regarding it from a European point of view, and it is certainly the earliest period for which we can reconstruct a map of land and sea with anything like an approach to accuracy.

I have therefore prepared a map of Northern Europe in Lower Devonian time (Fig. 80) and will briefly recapitulate the data on which the southern boundary or coast-line of the continent has been drawn. Beginning with the western region the great thickness of detrital deposits and the prevalence of fine sand in Brittany, Cornwall, and the south-west of Ireland are plain indications that they must all have been on the borders of a large area of land. We find actual portions of this land in Waterford, Wexford, and South Wales, and again in the southern part of Cornwall. Hence we arrive at the conclusion that the area in which the Glengarriff Beds were deposited was a large land-locked bay bounded by continental land on the north, west, and south, and only opening eastward through a channel from 50 to 70 miles in width.

From Cornwall the land seems to have projected as a promontory into the area now occupied by the English Channel, and its southern shore must have passed outside Brittany and then south-westward toward the north of Spain. In Asturia the lowest

Shardlow's Great Atlas, London.

FIG. 80.—RESTORATION OF THE GEOGRAPHY OF EUROPE IN THE LOWER DEVONIAN EPOCH.

600 feet of the Devonian are hard quartzitic grits and slates of the Plougastel and Glengarriff facies, but from their much smaller thickness we may conclude that the Atlantic land did not reach quite so near to Spain as it did to Brittany, the coast-line probably curving away to the west.

Returning to England it may be noted that rocks containing Upper Devonian fossils have been found in borings at Turnford, near Cheshunt, and below London, but they do not help much in our present quest. In the Ardennes, however, we find definite evidence of the position of the coast-line in Lower Devonian time, for the entire absence of the Lower Series in the basin of Namur proves it to have been land while that of Dinant was covered by the Lower Devonian Sea.

Here it must be pointed out that the supposed existence of land to the south of Dinant and Fepin, with a narrow strait between it and the northern mainland, is founded on a misapprehension of the facts. There was land there in Silurian times, and the basal conglomerate and sandstones of the Devonian testify to its destruction, but there is no overlap of successive stages against a slope of older rocks, and there can be little doubt that the whole mass of the Lower Devonian strata in the basin of Dinant passed over the massifs of Rocroi and Charleville; in other words, that this land of Silurian and Ordovician time sank beneath the waters of the Devonian Sea.

The same sea spread eastward over the greater part of Germany, but the great thickness and sandy nature of the Lower Devonian of the Harz Mountains testify to the proximity of land; and when we reach Poland still clearer indications are found, for there a break and unconformity between Silurian and Devonian presents itself, and we have in the Lowest Devonian deposits an intercalation of marine strata with sandstones of the Old Red facies, as if a large lagoon were being invaded by the sea. The same conditions are present in Eastern Galicia, which must likewise have lain near the margin of the continent, but in the Baltic provinces of Russia we clearly stand on firm Devonian land (see p. 223).

The line drawn on Fig. 80 to indicate the eastern border of this continent is, of course, merely an approximation to its true course; at present we only know that the land did not extend into Central Russia, and that it did not include Novaya Zembla.

In Middle Devonian time there seems to have been a general subsidence, enabling the Southern Sea to extend itself over some of the southern and eastern portions of the northern continent. Moreover, it seems that the areas invaded and covered by the Eifelian Sea were of much larger extent in the eastern than in the

western parts of the continent; consequently we must suppose that either the subsidence was greater in the east than in the west, or that there were larger areas of low-lying land in the east. The first hypothesis seems the most probable because the lacustrine area of South Wales lay so close to the border of the continent that we can hardly imagine it to have been at a high level above the sea, nor is the intervening isthmus likely to have been very high along its whole length.

The Orcadian basin is indicated on the map (Fig. 80), although we have no proof of its existence as a basin of deposition during Lower Devonian time. It may have existed in the form of a wide valley which, by subsequent disturbances and alterations of level in the northern part of the continent, was converted into a large lake-basin. In any case we must suppose that the river which ran out of this lake opened somewhere into the Middle Devonian Sea, for it can only have been by means of the ex-current river that the fish made their way into the lake, ascending it as salmon do rivers at the present day. Whether this river flowed eastward or northward is the question, but unless it traversed the range of mountains which certainly then existed in Scandinavia it must have taken a northerly course into a northern sea.

The lapse of time indicated by the slow accumulation of the Middle Devonian shales and limestones must have been very great, and it must not be estimated by the small thickness of such deposits in Brittany and Cornwall, but by their maximum development, which is probably that to be found in the Ardennes and the Rhenish provinces (see p. 215).

Again, it is noteworthy that if we had nothing but the succession of marine deposits as a record of the Devonian period, we should unquestionably have supposed that the whole period was one of quiet and uninterrupted subsidence, and that the epoch of the Middle Devonian merged into that of the Upper Devonian without any great physical change.

The terrestrial deposits, however, furnish us with evidence of a great change, though it is quite possible that this was accomplished without any great surface or subterranean disturbances. The change probably involved some movement of the earth's crust, but this can hardly have been elevation, for it ushered in the subsequent subsidence of Carboniferous time; neither was it immediate subsidence, or we should have had marine beds in the place of the Kiltorcan Beds and Upper Old Red of Wales. Rather it seems to have been a change in the climate and in the terrestrial conditions of deposition.

It is possible that toward the close of Middle Devonian time

dry and desert conditions prevailed over the central parts of the continent, including the British region; that the lakes shrank to small proportions, if they were not entirely dried up. On this supposition the change which took place may have been a return to more humid conditions, an increase in the rainfall, especially on the mountain ranges, resulting in the birth of torrential streams at certain seasons, which swept out the stones and pebbles that had accumulated in the higher valleys and spread them out on the desert plains, for there is sufficient evidence that the Caledonian area at any rate was such a desert plain.

As the annual rainfall increased, lakes were once more formed, and were again peopled with fish, but new kinds of fish had in the meantime been developed in the surrounding sea, so that the fish of the Upper Devonian lakes were a very different assemblage from that which lived in the older lakes. Finally we have evidence of a slow subsidence of the whole region and of the invasion of these lakes by the waters of a Carboniferous Sea.

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CHAPTER IX

THE CARBONIFEROUS SYSTEM

THE materials for a history of this period are more ample than those available for the preceding periods. Carboniferous rocks occupy a larger part of the British Isles than the rocks of any other system, and in the search for coal they have also been more extensively studied and explored, so that it has become possible to trace the lateral changes which the component members of the system undergo, and to correlate the strata of different districts with much greater accuracy. Carboniferous strata have also a considerable extension in France, Belgium, Germany, Silesia, and Russia as well as in Spain.

The records of the period are indeed more complete on the continent than they are in the British Isles, for they carry the history of it to a later date in geological time. Continental geologists have found it necessary to divide the whole system into three series, of which only the two older are represented in Britain, so that we have been accustomed to regard the Carboniferous System as consisting of these two, a Lower Carboniferous and an Upper (or Coal-measure) Series. The advance of comparative geology makes this view and our insular nomenclature no longer tenable, and we must either give new names to the British divisions or accept those current on the continent.

Dr. Vaughan has proposed the name *Avonian* for the southern type of the Lower Carboniferous, and the name *Bernician* has been used for the northern facies.^a No good name has yet been proposed for the rest of the British Series.

French geologists have adopted the name *Dinantian* for their Lower Carboniferous Series, but it is less comprehensive than the British *Avonian*. For the higher stages it will be convenient to adopt their names, and others again are used by Russian geologists

^a It was first proposed by S. P. Woodward (1856) for the whole Lower Carboniferous Series, and afterwards by Lebour (1877) for the greater part.

as their facies of the system is almost wholly marine. The nomenclature will therefore be as follows :—

England.	France.	Russia.
Westphalian.	Stephanian.	Uralian.
Avonian.	Westphalian.	Moscovian.
	Dinantian.	Dinantian.

In England, France, and Belgium, as well as in Russia, the *Avonian* consists almost entirely of marine deposits, and in most districts it is mainly composed of limestone. In Germany, on the other hand, it consists of carbonaceous shales with beds of sandstone and has long been known as the Culm. The *Westphalian* is everywhere (except in Russia) a varied succession of sandstones, shales, clays, and coal-seams, which seem to have been deposited on the borders of a sinking land, in deltas and lagoons, where the water was sometimes saline and sometimes brackish or fresh. The *Stephanian* is also a Coal-Measure Series of similar character in the west of Europe, but passes eastward into the marine *Uralian* of Russia.

As each of these great series has in some places a thickness of 9000 to 10,000 feet, and as the fauna and flora of each differs considerably from that of the others, it will be convenient to describe them separately and in succession.

I. THE AVONIAN SERIES

A. LIFE OF THE EPOCH

Plants are naturally not common fossils in marine deposits, so that the number known from this series is not large. The flora is almost the same as that of the Upper Devonian, and the following are the principal genera :—

Archæocalamites (= *Bornia*), *Cheirostrobis*, *Sphenopteris*, (*S. affinis* and *S. elegans*), *Adiantites*, *Rhacopteris*, *Cardiopteris*, *Heterangium*, *Lepidodendron*, *Lepidophloios*, and *Pityx*.

The Dinantian fauna is a rich one, both in genera and species. The following is a brief account of it, new generic appearances being marked with an asterisk.

Hydrozoa.—*Chaetetes*.

Foraminifera.—These become very abundant in the rocks of this period and contribute largely to the formation of some of the limestones, the principal genera being *Saccammina*, *Endothyra*, *Fusulina*, *Trochammina*, *Valvulina*, and *Lagena*.

Anthozoa.—Of corals the most common genera are *Aulo-*

Fig. 81.—GROUP OF CARBONIFEROUS FOSSILS (AVONIAN).

a. <i>Syringothyris cuspidata</i> .	f. <i>Posidonomya Becheri</i> .
b. <i>Productus giganteus</i> .	g. <i>Modiola Macadami</i> .
c. <i>Woodocrinus macrodactylus</i> .	h. <i>Phillipsia derbiensis</i> .
d. <i>Conocardium aliforme</i> .	i. <i>Lithostroton basaltiforme</i> .
e. <i>Glyphioceras sphaericum</i> .	m. <i>Aviculopecten sublobatus</i> .
n. <i>Euomphalus pentagonalis</i> .	

phyllum,* *Lithostrotion*,* *Lonsdaleia*,* *Phillipsastrea*, *Syringopora*, *Clisiophyllum*,* *Dibunophyllum*,* *Cyclophyllum*,* *Cyathaxonia*,* *Michelinia*, *Zaphrentis*, *Amplexus*, *Caninia*, and *Cyathophyllum*. None of these survive the Carboniferous period in Europe, though a few occur in the Permian of Asia.

Echinoderma.—Crinoidea are abundant, and their remains often form a large part of the limestones. The chief genera are

Fig. 82.—GROUP OF CARBONIFEROUS FOSSILS (AVONIAN).

- a. *Michelinia megastoma*.
- b. *Amplexus coralloides*.
- c. *Lithostrotion affine*.

- d. *Terebratula* (*Dielasma*) *hastata*.
- e. *Spirifer striatus*.
- f. *Productus semireticulatus*.

Actinocrinus,* *Platycrinus*, *Rhodocrinus*, *Cyathocrinus*, *Poteriocrinus*, *Amphorocrinus*,* and *Woodocrinus*.* None of them, with the possible exception of *Cyathocrinus*, survived this period. Blastoidea now seem to take the place of the Cystideans of the older Palaeozoic rocks, the commoner genera being *Granatocrinus*, *Codaster*, and *Orophocrinus*. Of Echinoidea there are *Archæocidaris*, *Palæchinus*, and *Melonites*.

Crustacea.—The only surviving genera of trilobites are

Phillipsia, *Griffithides*, *Proetus*, *Cyphaspis*, and *Brachymetopus*. None are common, all are small, and all died out, in Europe at any rate, before the close of the period. Small Ostracoda are often abundant belonging to the genera *Bairdia*, *Cypridina*, *Cypridinella*, and others. *Dithyrocaris* and other Phyllocarids also occur. Schizopoda are also represented and are common in some parts of Scotland.

Fig. 83.—GROUP OF CARBONIFEROUS FOSSILS (AVONIAN).

a. *Platycrinus lævis*.

b. *Palaechinus gigas*.

c. *Granatocrinus ellipticus*.

d. *Phillipsia pustulosa*.

e. *Coelonautilus cariniferus*.

f. *Gastrioceras Listeri*.

g. *Orthoceras Gesneri*.

Brachiopoda.—The only common and distinctive Carboniferous genus is *Seminula*, but most of the Devonian genera survive, such as *Orbiculoidea*, *Productus*, *Spirifer*, *Spiriferina*, *Rhynchonella* (*Pugnax* and *Hypothyris*), *Cammarophoria*, *Dielasma*, *Athyris*, *Chonetes*, and *Orthis*.

Lamellibranchia.—The following are some of the commoner genera, those with an asterisk making their first appearance: *Pterinopecten*, *Aviculopecten*, *Crenipecten*, *Posidoniella*, * *Parallelodon*,

Conocardium, *Myalina*, *Schizodus*,* *Leptodomus* (*Protoschizodus*), *Edmondia*, *Cardiomorpha*, *Pleurophorus*, *Cypricardiella*,* and *Sanguinolites*.*

Gastropoda.—Most of the Devonian genera continue, and the commoner are: *Metoptoma*, *Pleurotomaria*, *Murchisonia*, *Bellerophon*, *Euomphalus*, *Straparollus*, *Naticopsis*, *Capulus*, *Loxonema*,

Fig. 84.—GROUP OF CARBONIFEROUS FOSSILS (AVONIAN).

a. *Orthis resupinata*.
b. *Aviculopecten papyraceus*.
c. *Cardiomorpha oblonga*.

d. *Conocardium hibernicum*.
e. *Euomphalus pentagonalis*.
f. *Bellerophon tangentialis*.

Macrochilus, and *Turbonitella*, but very few of these survive the close of the Carboniferous period.

Cephalopoda.—The following are some of the genera which occur: of Nautiloidea there are *Orthoceras*, *Actinoceras*, *Cyrtoceras*, *Poterioceras*, *Temnocheilus*,* *Cælonautilus*,* *Vestinautilus*,* *Stroboceras*,* *Discites*; of Ammonoidea the following genera belonging to the Goniatitidæ, *Brancoceras*, *Pericyclus*,* *Gastrioceras*, *Glyphioceras*, *Nomismoceras*,* *Dimorphoceras*,* *Prolecanites*,* *Pronorites*.*

Pisces.—Remains of fish are very numerous, and a long list of names founded on the teeth and spines of fish might be given, but the following are known from more complete remains, *Eurynotus*, *Rhizodus*, *Holoptychius*, *Megalichthys*, *Cœlacanthus*, *Platysomus*. Many of the Carboniferous fish were Elasmobranchs, and most of the remainder are Teleostomi of the Crossopterygian order.

A remarkable fact in the distribution of the marine fauna is the persistence of many species throughout the whole of the Avonian Series. Recent studies of the corals and Brachiopoda have, however, shown that a few species are restricted to certain horizons and that others are much more abundant within certain zonal limits than they are above or below, and in this way a zonal classification of the great mass of limestones has been established.

The following are some of the most common and characteristic species of the Dinantian Series as a whole :—

- Foraminifera.* Saccamina frontiniformis (syn. Carteri), Trochamina incerta, Endothyra.
- Hydrozoa.* Chætetes tumidus.
- Actinozoa.* Amplexus coralloides, Cyathophyllum regium, Lonsdaleia floriformis, Clisiophyllum bipartitum, Dibunophyllum turbinatum, Cyathaxonia cornu, Phillipsastrea radiata, Syringopora geniculata, Lithostrotion affine, L. basaltiforme, L. striatum, Zaphrentis Phillipsi, Caninia cylindrica, Michelinia favosa, and M. megastoma.
- Bryozoa.* Fenestella flabellata, Ceriopora gracilis.
- Echinoderma.* Actinocrinus triacontodactylus, Amphoracrinus amphora, Platycrinus lævis, Poteriocrinus crassus, Woodocrinus macrodactylus; Archæocidaris Urei, Palæchinus sphericus, Pal. gigas, Orbitremites derbiensis.
- Brachiopoda.* Athris (Seminula) ambigua, A. (Seminula) ficoides, A. (Cliothyris) Roissyi, Orthis resupinata, Spirifer striatus, S. clathratus, Syringothyris cuspidata, Productus semireticulatus, P. giganteus, Dielasma hastatum, Rhynchonella (Hypothyris) pleurodon, R. (Pugnax) acuminata, Spiriferina octoplicata.
- Lamellibranchia.* Conocardium aliforme, C. hibernicum, Pterinopecten papyraceus, Pt. sublobatus, Pt. granosus, Edmondia sulcata, Modiola Macadami, Myalina crassa, Cardiomorpha orbicularis, C. oblonga, Posidonomya Becheri.
- Gastropoda.* Euomphalus pentangulatus, Naticopsis plicistria, Pleurotomaria carinata, Murchisonia verneuilliana, Platyceras neritoides, Bellerophon Urei, B. tangentialis, Macrochilus ovalis, Capulus vetustus.
- Cephalopoda.* Cœlonautilus cariniferus, Cyrtoceras Gesneri, Orthoceras undulatum, Actinoceras giganteum, Poterioceras fusiformis, Glyphioceras diadema (= crenistria), G. sphericum, Pronorites cyclolobus.

<i>Trilobita.</i>	<i>Phillipsia pustulosa</i> , <i>Griffithides globiceps</i> , <i>Brachymetopus uralicus</i> .
<i>Entomostraca.</i>	<i>Leperditia</i> Okeni.
<i>Pisces.</i>	<i>Eurynotus crenatus</i> , <i>Rhizodus Hibberti</i> , <i>Elonichthys Robisoni</i> , <i>Cladodus striatus</i> , <i>Cochliodus contortus</i> , <i>Orodus ramosus</i> , <i>Petalodus acuminatus</i> , <i>Psammodus rugosus</i> .

B. BRITISH AVONIAN STRATA

The surface areas occupied by the Lower Carboniferous or Avonian Series in the British Isles are shown on most geological maps. They are clearly shown on the cheap (2s.) Index map of the Geological Survey, and most of them are indicated in the maps (Figs. 87 and 94) of this volume. The large extent of the area which they occupy in Ireland is especially noticeable, though the student must remember that in Fig. 94 the superjacent Coal-measures are not shown.

In England it is probable that the limestones extend eastward under large parts of the southern and central counties, but they do not appear to exist in the East Anglian counties, where many borings have been made at different times, but have always found rocks of pre-Carboniferous age beneath the cover of Cretaceous strata.

With regard to the superposition and relation to the older rocks it may be stated generally that the Carboniferous strata follow those of the Upper Devonian or Upper Old Red Sandstone in conformable succession wherever the latter are present; but when these are absent, the Carboniferous rests unconformably upon the older formations.

With respect to the subdivisions of the Avonian Series recent studies by Dr. Vanghan, Dr. W. Hind, and Professor Garwood have shown that it is everywhere divisible into two stages, and as French geologists had already made two similar divisions, their names have been adopted, namely *Tournaisian* for the lower and *Viséan* for the upper stage. In England each stage appears to be divisible into three zones, but the delimitation of these zones has not yet been determined in all districts. Where fully developed, the normal succession is as follows:—

Viséan—	{	Dy. <i>Cyathaxonia</i> sub-zone.
	{	D. <i>Dibunophyllum</i> zone.
	{	S. <i>Seminula</i> zone.
Tournaisian—	{	C. <i>Syringothyris</i> zone.
	{	Z. <i>Zaphrentis</i> zone.
	{	K. <i>Cleistopora</i> zone.

It should be stated that Dr. Vaughan regards the *Cyathaxonia* Beds and their equivalents as a sub-zone of the *Dibunophyllum* zone, but as these equivalents include the Yoredale Beds of Yorkshire and a great part of the "Pendleside Series" of Dr. Hind, which possesses a peculiar fauna of its own, it seems desirable to give special prominence to them in a general scheme, though they are poorly represented near Bristol.

For convenience of description the more or less different facies which the Avonian Series presents in different parts of the British Isles will have to be treated under seven heads, viz. (1) Bristol and South Wales, (2) North Wales and Derbyshire, (3) South Lancashire and Yorkshire, (4) North Lancashire and Westmoreland, (5) Northumberland and Berwick, (6) Scotland, (7) Ireland.

1. Bristol and South Wales

The zonal study of the limestone series of the Bristol district by Dr. Vaughan¹ has made it the typical exposure of that series in Britain. The succession is there complete from the base to the top of the *Dibunophyllum* zone (D_2), but no calcareous representative of the *Cyathaxonia* zone (D_3 and D_4) occurs in the Mendip or Bristol districts, and its equivalent must be sought in the sandstones which form the lower part of the so-called "Millstone grit."

The actual thickness of the Limestone Series varies greatly in different parts of the area; it is thickest in the Mendip Hills, rather less at Clifton, and much thinner to the northward. Lithologically the series has been divided into four parts, which, with their varying thicknesses, are given below:—

	Mendips.	Clifton.	Wickwar.
Upper limestones and shales	1200	1200	830
Middle shales and oolitic limestone	250	300	520
Lower limestones (encrinital)	1200	500	
Lower shales	450	400	320
	<hr/> 3000	<hr/> 2400	<hr/> 1670

Dolomitisation is prevalent in the middle part of the series, and affects a greater and greater portion as the beds are followed northward. The lithology of the strata is, however, only of local importance, while the zonal divisions established by Dr. Vaughan form a standard by means of which the limestones and shales of other areas, whether they are in similar or dissimilar sequence, can be compared with the Avon section.

The *Clestopora* zone is coextensive with the lower shales, and is divisible into two portions, the lower 100 feet forming the phase

of *Modiola* (cf. *lata*), and the higher beds containing *Productus bassus*, and near the top an abundance of *Cleistopora geometrica*, a small compound coral of Michelinoid aspect.

The Zaphrentis zone consists of encrinital limestones characterised in the lower part by an abundance of *Spirifer clathratus*, and in the upper part by *Zaphrentis Konincki*.

The Syringothyris zone consists largely of dolomitic and oolitic limestones in which *Caninia cylindrica*, *Michelinia cf. megastoma*, and *Spirifer (Syringothyris) cuspidatus* are common and characteristic fossils. *Caninia patula* marks a lower, and *Cyathophyllum* (sp. ϕ) an upper sub-zone.

The Seminula zone consists of limestones with shale-partings in the lower part, and beds of pisolitic limestone in the upper. The index fossil is the Athyrid *Seminula ficoides*, but *Productus corrugato-hemisphericus* is common, as also are massive and dendroid *Lithostrotions* and *Carcinophyllum*.

The Dibunophyllum zone consists of limestones, shales, and occasional grits. It is characterised by the abundance of highly developed corals: *Dibunophyllum* (simple in the lower and advanced in the upper sub-zone; *Lithostrotion irregulare*, *Cyathophyllum Murchisoni* are common forms; *Lonsdaleia floriformis* and *Cyathophyllum regium* mark the upper sub-zone.

At Wickwar, near the northern end of the Bristol coalfield, the limestone series is reduced to 1670 feet, and farther north, in the Forest of Dean area, it is less than 600 feet. In the last-mentioned area the highest limestones are of Seminula age, and are succeeded conformably by sands and quartz-pebble conglomerates that have been referred to the "Millstone grit" although they are of considerably earlier age than the base of the typical Millstone grit of the Midlands and Yorkshire.

In South Wales, at the eastern end of the coalfield, the Avonian Series, with shales at base and summit, is about 1000 feet thick near Cardiff and Newport, but thins northward to less than 500. (The series is, however, incomplete at the top as Millstone grit lies unconformably upon *Seminula* and Lower *Dibunophyllum* Beds.) Westward, near Rhymney, and in the Gower Peninsula, the Avonian attains a thickness of 3000 feet. There the black shales and limestones² above the *Dibunophyllum* limestone (see Fig. 77) yield a peculiar fauna, including the Goniatites *Glyphioceras bilingue*, *G. spirale*, and *G. reticulatum*. These are characteristic species of the Pendleside Beds of Lancashire and North Stafford, and belong to a zone or sub-zone which lies between the *Dibunophyllum* zone of the Bristol area and the typical Millstone grit of the Dovedale country.

In Pembrokeshire all the zones are well developed, and are finely exhibited in the coast sections. At Skrinkle Haven the junction of Old Red Sandstone and basal Carboniferous is well shown; the central beds constitute the Tenby anticline, and the "Pendleside" Beds are found north of that place, where they consist of black carbonaceous shales with large ellipsoidal concretions, locally known as bullions. These beds contain *Glyphioceras diadema*, *Pterinopecten papyraceus*, and *Posidoniella membranacea*.

2. North Wales, Stafford, and Derby

The great difference between the limestone series of this area and that of South Wales and Gloucestershire is that it belongs entirely to the Viséan stage, the basal beds being on the horizon of the upper part of the Seminula zone; so that there is no representative of the Tournaisian stage.

The lithological divisions were studied and described by Mr. G. H. Morton and Dr. A. Strahan, while the palæontological zones have recently been worked out by Dr. W. Hind and Mr. J. T. Stobbs.³ The most complete sequence is found in Flintshire, and this is given in the following table:—

Lithological Divisions.	Zones.	Thickness.
Holywell shales Teilia Beds	} <i>Posidomya Becheri</i>	} 1000
Cherty sandstones		
Aberdo limestone	} Upper <i>Dibunophyllum</i>	} 450
Grey limestone		
White limestone	} Lower <i>Dibunophyllum</i>	} 1100
Brown limestone		
Basal conglomerate	} <i>Seminula</i>	} 450
		—————
		About 3000

The absence of *Caninia* makes it fairly certain that only the top of the Seminula zone comes into the succession. The lower part of the *Dibunophyllum* zone is marked by the presence of that genus with *Cyathophyllum Murchisoni*, *Productus hemisphericus*, and *P. cora*. The higher part contains all the typical fossils of its Bristol equivalent, and the species of *Lithostrotion* are common, as are also several species of *Spirifer* and *Schizophora resupinata*. The sandy beds at the top of this zone consist of compact fine-grained sandstone, each bed having a medial band of grey or black chert which is full of sponge spicules. These beds and the Aberdo limestone are regarded as a separate sub-zone characterised by the coral *Cyathozonia* and *Productus longispina*. They form a passage into the overlying stage.

GEOLOGICAL MAP OF THE NORTHERN PART OF ENGLAND

Fig. 87.

The true position of the Holywell shales was first indicated by Dr. Hinde, and the group is undoubtedly the equivalent of his Pendleside Series. In Flintshire it consists, in the lower part, of black shales with layers of black limestone and chert, yielding the bivalves *Posidonomya* and *Pterinopecten*, while the higher part is composed of soft shales in which *Posidoniella laevis* is common.

Southwards all these beds decrease in thickness rather rapidly, and they finally thin out south of Oswestry, only the higher part of the limestone with *Prod. giganteus* appearing again for a short distance in Shropshire, near Lilleshall. Westward the whole series is faulted down into the Vale of Choyd, and portions of it occur along the coast; thus, in the Orme's Head promontory near Llandudno, the greater part of the limestone series is found with a thickness of 1150 feet, though neither the base nor the summit is seen. In Anglesey tracts occur on the border of the Menai Strait, and a larger one is faulted into the central part of the island; the lowest limestones here belong to the white division, and in places they include beds of white sandstone and conglomerate from 90 to 100 feet thick.

In North Staffordshire and Derbyshire the zonal succession has recently been determined by Mr. Sibly, and found to be as follows:—

		Feet.
D ₃	4. Shales and thin beds of black limestone (Yoredale Beds)	400
D ₂	3. Grey and white limestones containing layers of chert (sub-zone of <i>Lonsdaleia floriformis</i>)	600
D ₁	{ 2. Massive white limestones with interbedded lava-flows (toad-stones)=Dibnophyllum Beds.	600
	1. Dark limestones	seen for 800
		<hr/> 2400

The actual base is nowhere exposed, and consequently the total thickness of the series is unknown, but it is doubtful whether it exceeds 3000 feet even in the centre of the area. The whole of the series thins out to the south-west before reaching the South Staffordshire coalfield, but continues toward the south-east beneath the small Leicestershire coalfield and wraps round the pre-Cambrian rocks of Charnwood Forest.

The limestones which compose the "Mountain limestone" of Derbyshire vary much in lithological character,⁴ some consisting mainly of broken fragments of crinoids and shells, others of corals and coral debris, and others being compact and foraminiferal, while in many parts the organisms have been obscured or destroyed by the chemical changes of marmorisation or dolomitisation.

The upper surface of D₂ shows signs of contemporaneous

erosion, and is overlain by a bed of rolled shells and limestone pebbles with occasional quartz pebbles; it was first found at Castleton, but has since been traced by Dr. W. Hind through the whole of Derbyshire and North Staffordshire. It contains many Brachiopods, trilobites, and teeth of *Psammodus*, *Psephodus*, etc., and shows that the current which brought the muddy sediment of the overlying shales was at first strong enough to break up and destroy some of the previously formed limestone, which at that time was, of course, in an unconsolidated condition.

The shales above mentioned are termed the Yoredale shales by the Geological Survey and the Pendleside shales by Dr. W. Hind, but as we shall presently see that the two groups are contemporaneous and not successive, as Dr. Hind supposed, it does

Fig. 88.—SECTION THROUGH CONGLETON EDGE (by W. Gibson and W. Hind).

h, i. Millstone grits.

g. Pendleside shales.

b to f. Grit, tuff, limestone, and shale.

a. Main Avonian limestone.

not matter which name they bear. The relation of these shales to the limestone below and the Millstone grit above is shown in Fig. 88.

3. South Lancashire and Yorkshire

The Avonian Series is brought up again from beneath the Millstone grits in Lancashire and West Yorkshire (see map, Fig. 87) by an anticlinal flexure which runs in a north-easterly direction from near Blackburn by Clitheroe to Skipton, with a more northerly prolongation by Cracoe across Wharfedale by Burnsall. From these places this division of the system spreads northward and occupies a large irregular tract of ground varying from 15 to 30 miles in width through Yorkshire, Durham, and the eastern parts of Westmoreland and Cumberland.

The rocks of this large area present two different facies, one in the south-west, which has been called the Lancashire or Clitheroe type, and the other to the north, which is known as the Yoredale type. Moreover, the transition from one to the other is rapid, and coincides closely with the line of the Craven fault, which runs obliquely across the area from near Kirkby Lonsdale by Ingletton, Stainforth, and Linton. South of this line the beds

attain a great thickness and their base is nowhere exposed; north of it the base is exposed in several places, resting on a floor of upturned Ordovician and Silurian rocks, but the series is much thinner (see Fig. 90).

For the following comparative view of the succession in the two areas I am indebted to Dr. Vaughan.

Clitheroe District.		Feet.	Ingleton District.		Feet.
M.G.	Millstone grit (4th grit).		} Shales	Millstone grit (4th grit).	
	Bowland shales . . .	50 to 800			100
	Pendle grit . . .	0 to 300	} Yoredale Beds		
	D ₇ . Pendleside limestone .	100 to 400			400
	D ₂ . Pendleside shales . . .	1200	} Sear limestones Basement Beds }		800
S & D ₁ . Clitheroe knoll-limestones .		2800			

The Clitheroe and Cracoe limestones have not yet been completely zonalised, but Dr. Vaughan informs me that the main Clitheroe knolls include representatives of D₁ and of S (Seminula zone), and that the beds at the base of the main knolls belong to C₂ (Syringothyris zone), but there is a considerable thickness of limestone below that horizon.

Near Ingleborough the lowest beds are not older than the top of the Syringothyris zone, and the total thickness of Viséan limestones is only 600 feet.⁵ Northward, however, they thicken again considerably till near Kirkby Stephen there is 3700 feet of them. Then they again diminish by the rapid thinning out of the lower beds till in the Cross Fell district they are once more reduced to 600 or 700 feet, and much of this is sandstone. Fig. 91 illustrates the position and composition of the Viséan Group at Ash Fell and Roman Fell, east of Appleby, and the map (Fig. 89) shows the course of the buried ridge of Ordovician rocks which causes this thinning-out—a ridge which forms a natural northern limit to the region we are describing.

Returning now to the north-east of Lancashire the higher stage, comprising the Pendleside and Yoredale Beds, remains to be dealt with. The succession of beds forming the Pendleside Group was fully described by Dr. W. Hind,⁶ and is given above; the black Pendleside shales are characterised by *Posidonomya Becheri* and *Pterinopecten papyraceus*, and the Pendle limestone by the same with *Glyphioceras spirale* and *G. reticulatum*. In the Clitheroe and Pendleside districts the total thickness of this group is at least 2500 feet, but it thins northward, and when the Settle faults are crossed its place is taken by such a different set of beds that the identity of the two groups has been for a long time in

doubt. This year (1911), however, Mr. Cosmo Johns⁷ has published evidence which seems to show that the Pendle limestone is the equivalent of the "main limestone" near the top of the Yoredale Beds.

The Yoredale Beds consist of limestones with intercalated bands of shale and sandstone, the limestones being persistent bands which have been traced for long distances, and each band has received a special name. The highest of the Yoredale limestones is known

Stanford's Geog^l Estab^l, London.

Fig. 89.—MAP OF THE NORTH-WESTERN COUNTIES TO SHOW THE POSITION OF THE PRE-CARBONIFEROUS RIDGE (Goodchild).

as the "main limestone," and the lowest as the "Hardraw limestone." Between these at Ingleborough there are three other limestones, and farther north two others come in, so that in Wensleydale there are seven Yoredale limestones.

Dr. Vaughan informs me that the fauna of the Yoredale Beds is identical with that of the upper part of the Dibunophyllum zone of Bristol (D_2), and thus, if the beds are the equivalents of the Lower Pendleside Group, the latter must have been formed under different bathymetric conditions.

Above the "main limestone" of Wensleydale there are some peculiar beds which, though of no great thickness (160 feet), are

remarkable both in their lithological and palæontological characters. They include two beds of limestone, each of which is overlain by a band of chert-beds; the lower set is known as the "Red Beds," and the upper as the "Crow limestone and chert." The chert in the Red Beds is 42 feet thick, and has yielded a remarkable set of fish teeth, an account of which, with a complete enumeration of the beds at Leyburn in Wensleydale, has been published by Mr. J. W. Davis.

4. North Lancashire and Westmoreland

The area occupied by Avonian limestones in this district is shown on the map (Fig. 87), and the beds have been recently studied and classified by Professor Garwood, who finds representatives of both the Tournaisian and Viséan stages.⁸ The fauna, however, contains some special elements, and the relative abundance of species is different from that prevailing near Bristol, so that he found it well to make different zonal divisions, though these can be roughly correlated with the southern zones. The following table is copied from that given by him :—

	Zones.	Subzones.	
Beds with <i>Lithostrotion</i> .	<i>Dibunophyllum</i> <i>Productus corrugato-hemisphericus</i> and <i>Spiriferina laminosa</i>	{ Upper (?) Middle { <i>Productus latissimus</i> and <i>Lonsdaleia floriformis</i> Lower { <i>Cyathophyllum</i> <i>Murchisoni</i> { Upper { <i>Nematophyllum minus</i> <i>Cyrtina carbonaria</i> Lower { Gastropod Beds <i>Clisiophyllum keyserlingi</i> at base	D ₃ D ₂ D ₁ S ₂ S ₁
Beds without <i>Lithostrotion</i> .	<i>Michelinia megastoma</i> <i>Athyris glabristria</i>	{ Upper, <i>Daviesiella carinata</i> Lower { <i>Camarophoria</i> <i>isorhyncha</i> { Upper, <i>Seminula gregaria</i> Lower, <i>Solenopora</i>	C ₂ C ₁ γ Z ₂ ?
Basement Conglomerate.			

The lowest beds are shales and conglomerates found in Ravenstone

Dale and near Shap in Westmoreland, and it is these which he refers to the top of the Zaphrentis zone.

The lowest limestones are highly magnesian, and appear to have been deposited under lagoon-like conditions which encouraged the growth of calcareous algæ, especially *Solenopora*, and these have contributed largely to the formation of these beds.

Most of the Viséan limestones are rich in Foraminifera, *Saccammina* being abundant in the D zone. The highest beds are those of Humphrey Head (Morecambe Bay) and of Brampton near Shap. The full thickness is probably over 3000 feet, but lessens northward.

5. Northumberland and Berwick

From the buried ridge of older rocks which is indicated in Fig. 89 the thickness of the Avonian Series again increases; thus the main mass of the Viséan or Scar limestone becomes still further split up by the intercalation of beds of shale and sandstone till, near Alston, it has expanded from about 400 to 1600 feet, with twelve distinct bands of limestone. It has, in fact, assumed a facies similar to that of the overlying Yoredale Group.

Moreover, the series increases by the incoming of lower and lower beds, some of them representing Tournaisian stages, and at Alston these are 1000 feet thick and about 2000 on the Scottish border. This lower group contains but little limestone, and is largely arenaceous, so that the name of *Tuedian* was given to it in 1856 by Mr. G. Tate, from its fine development along the valley of the Tweed.

Similarly in 1877 Professor Lebour proposed the name *Bernician* for the compound facies which represents the higher limestones of the Viséan and the Yoredalian stage.

Probably the most convenient provincial classification of the series is that adopted in recent memoirs of the Geological Survey, but this now requires to be brought into line with the zonal classification of more southern areas, and with the "stage" divisions which have been used in the preceding pages. The zonal comparison has been accomplished in large part by Professor Garwood,⁹ and is indicated in the following table, except with regard to the higher beds, which, being the equivalents of the Yoredale Beds, must represent the highest part of the Dibunophyllum zone if Mr. C. Johns' views are correct:—

	Subdivisions.	Zones.	Stages.
Bernician Series.	<i>Upper Calcareous division</i> (from the Millstone grit to the top of the Oxford limestone). Sandstones and shales with some coals and one or more beds of marine limestone, 1200-2000 .	D ₃	Viséan.
	<i>c. Lower Calcareous division</i> (from Oxford limestone to base of Dun or Redesdale limestone). Sandstones and shales with coals and many beds of marine limestone, 800-1000 .	D ₂	
	<i>d. Carbonaceous division</i> (Sercmerston Beds). Strata prevalently carbonaceous; limestones chiefly thin, many containing carbonaceous matter; many coal-seams, 800-2500 .	D ₁	
Tuedian Series.	<i>c. Upper Tuedian or Fell Sandstone Group</i> : a belt of massive grits with green, grey, and reddish shales; coals rare and thin, 500-1600 .	S	Tournaisian.
	<i>b. Lower Tuedian or Cement-stone Group</i> : sandstones and shales with bands of cement-stone passing into limestones near Rothbury and Bewcastle, 500-1500 .	C	
	<i>a. Basement conglomerates</i> (Upper Old Red Sandstone), 0-500 .	? Z	

Tuedian Series.—*a.* The basement conglomerates occur locally round the Cheviot Hills, and are by some referred to the Upper Old Red Sandstone, but they pass up into the overlying sandstones, and certainly form a local base of the Carboniferous System. They are of a reddish-brown colour, and contain rolled pebbles of the Cheviot porphyrites.

b. This group consists of yellow and reddish sandstones, grey and purple shales, greenish sandy clays (sometimes full of hard siliceous concretions), and beds of hard cream-coloured earthy limestone or cement-stone. In these beds fossils are rare and badly preserved, but *Modiola Macadami* occurs. Near the top are limestones in which Professor Garwood has found *Syringothyris cuspidata*, *Athyris glabristria*, and *Orthotetes crenistria*, and these are sufficient to indicate the zonal age.

c. The Fell sandstones form a broad belt of high and rugged country in the west of Northumberland, rising into craggy hills such as those of the Chillingham and Simonside Hills, and the Peel and Bewcastle Fells. These sandstones are divided by bands of shale, and a few thin seams of coal occur. The fossils are chiefly plant remains, but *Archæanodon Jukesi* has been found in the lowest (Harbottle) grit, and Professor Garwood has also discovered a few marine fossils in the lowest beds on the borders of Cumberland; these include *Camarophoria isorhyncha* and *Spiriferina lammosa*, which in Westmoreland are restricted to the lower part of the Seminula zone.⁹

Bernician Series.—On the southern border of Northumberland the Scar limestone of Yorkshire and the Yoredale Beds are still distinguishable as separate stages, but as they are followed northward they lose their distinctive characters and merge into one great series of alternating limestones, shales, and sandstones, with many workable beds of coal.

The most remarkable feature of this series is the great development of mechanical sediments in the centre of the county, some of the lower beds expanding into the "Carbonaceous" Group, and many fresh beds of sandstone and shale with coal-seams coming in above the Main Yoredale limestone to form the upper calcareous division, so that the whole is about 6000 feet thick, but again becomes thinner to the northward.

The *Carbonaceous* division has not yielded many marine fossils, but Professor Garwood has found *Spiriferina laminosa* with dendroid *Lithostrotions*, and the group is referable to D_1 . The lower calcareous group contains species of *Dibunophyllum* with *Cyathophyllum regium* and *Lithostrotion junceum*, so that its zonal age is evident, and it is noteworthy that several of the limestones are largely composed of the Foraminifer *Saccamina Carteri*.

The Oxford limestone is probably the equivalent of the Hardraw limestone of Durham, and if so the beds above this correspond with the Yoredale Group, but the Pendleside Cephalopoda have not yet been found. On the other hand, the corals *Lonsdaleia floriformis* and *Alveolites septosa*, with the Brachiopods *Productus giganteus* and *P. latissimus*, first appear in and above the Oxford limestone.

6. Scotland

The central lowlands of Scotland display a great thickness of Lower Carboniferous rocks which may be regarded as the equivalents of the Tuedian and Bernician Series of Northumberland, for the Scottish Series is similarly divisible into a lower group, which is mainly arenaceous, and an upper more varied group of shales, sandstones, limestones, and coals. The lower has been called the Calciferous Sandstone Series, and the upper was termed the Carboniferous Limestone Series, but the equivalents of the main mass of the Carboniferous limestone lie entirely below this "limestone series" of Scotland. Thus the nomenclature formerly used by the Geological Survey and adopted in most text-books gives rise to misconception and tends to exaggerate the stratigraphical importance of the upper part of the series. For while the upper portion, which has a thickness of only from 1600 to 1800 feet,

Fig. 92.—SECTION FROM THE HIGHLAND BORDER NEAR BEN LOMOND TO THE PENTLAND HILLS. Distance about 45 miles.

- 4. Coal-measures
- 3. The Limestone Series
- 2. Oil-shale and sandstone group
- 1. Red Sandstone Group
- z. Interbedded lava-flows.
- D. Lower Old Red Sandstone.
- C. Silurian rocks.
- B. Ordovician rocks.
- A. Highland schists.
- f.f. Faults.

Fig. 93.—SECTION ACROSS THE CASTLECOMER COALFIELD IN LEINSTER (Professor Hull). Distance 22 miles.

- g. Middle Coal-measures
- f. Lower Coal-measures
- e. Flagstone Group
- Westphalian Series.
- Avonian Series.
- d. Black Shale Group
- c. Upper limestone
- b. Middle limestone
- a. Lower limestone
- g. Granite of Carlow.

has been divided into three groups, the lower portion, which is nearly 6000 feet thick, was undivided.

According to the late J. G. Goodchild¹⁰ the lower portion is equally capable of division into three groups, which he called (1) the Ballagan Beds, (2) the Granton and Hailes sandstones, (3) the Oil-shale Group. He regarded the sandstone group as the equivalents of the Fell sandstones and the Oil-shales as corresponding with the Carbonaceous division of the Border counties. The Geological Survey has not entirely accepted this nomenclature,¹¹ but has included the massive sandstones in the Oil-shale Group because some thin oil-shales have been found in them. In the following table Goodchild's divisions are adopted as being convenient and lending themselves to correlation with Northumberland.

Average Thickness.	Scotch Divisions.	Northumberland.
500	<i>f.</i> Upper Limestone Group	} Yoredale Beds.
800	<i>e.</i> Edge Coal Group	
500	<i>d.</i> Lower Limestone Group	
2500	<i>c.</i> Oil-shale Group	Carbonaceous Group.
1500	<i>b.</i> Granton and Hailes sandstones	Fell sandstones.
1300	<i>a.</i> Cement-stone (or Ballagan) Beds	Cement-stone Beds.

Cement-stone Group.—In Edinburgh, Linlithgow, and Fife this consists in the lower part of clays, shales, sandstones, and tuffs with some beds of dull compact limestone (cement-stone) and of siliceous sinter; this part is about 200 feet thick. Next in the Edinburgh district comes the volcanic episode of Arthur's Seat, a set of basaltic lavas and tuffs with interstratified sandstones and shales, having a total thickness of 750 feet. These are covered by the Abbey Hill shales, which are 300 feet thick and contain marine fossils. The fossils in the lower part of the group are chiefly plant remains and small freshwater Crustacea (*Leperditia*, *Estheria*, *Bythocypris*, etc.), but at Belhaven, near Dunbar, a flattened form of *Modiola Macadami* occurs in hundreds.

In the Glasgow district this group has been called the *Ballagan Beds*, and there it consists entirely of sedimentary deposits, sandstones, shales, and argillaceous limestones, without any contemporaneous volcanic rocks, though the thickness is still from 1200 to 1500 feet.

Granton and Hailes Sandstones.—This group consists of two thick sandstones separated by a band of shales. The lower member is the Granton sandstone, probably about 800 feet thick; the central band consists of the Wardie shales (400 feet), and the upper is the Hailes sandstone, which may be 1000 feet thick. These sandstones form good building stones, but have yielded few

fossils; but the Wardie shales contain *Schizodus pentlandicus*, *Naiadites obesa*, *Anthracomya levis*, and others. These beds gradually thin westward till near Glasgow there is only 100 feet of such sandstone.

Oil-shale Group.—This group takes its name from the prevalence of black bituminous shales which contain large quantities of petroleum, some bands of them being so rich as to yield from 30 to 40 gallons of oil per ton of shale, besides a considerable quantity of sulphate of ammonia as a by-product in the process of abstraction.

Near Edinburgh there is a bed of oil-shale above the Hailes sandstone which makes a convenient base to the group, and about 900 feet above this is the Burdiehouse limestone, a bed of dark-grey limestone 20 to 30 feet thick and crowded with the cases of the small Ostracod *Leperditia Okeni* (var. *burdigalensis*). Another limestone band higher up is entirely composed of the shells of *Productus semireticulatus* and *P. longispinus*.

The group is most fully developed in Fifeshire, where it is over 3000 feet thick, containing many seams of oil-shale and no fewer than eighteen beds of limestone containing marine fossils; but the mass of the group consists mainly of shales and sandstones which contain the remains of fish, plants, and estuarine molluscs, especially *Naiadites obesa*. These sediments are interstratified with sheets of volcanic material—basalts and basaltic tuffs—and are pierced by a large number of pipes and bosses of volcanic agglomerate which are the orifices of small volcanic vents.

When followed westward by Stirling and Dumbarton to Renfrew and the Isle of Arran, the oil-shales become much thinner and are interstratified with lava-flows, which in some districts seem entirely to take the place of the sedimentary deposits.

Lower Limestone Group.—Near Edinburgh this group has a thickness of 400 feet to 500 feet, and contains three beds of limestones, but these are seldom more than 12 feet thick, though occasionally swelling out to 30 feet, and in the Bathgate Hills (Linlithgow) to 70 or 80 feet. In Ayrshire the Hurlet, or Main limestone, attains a thickness of 100 feet. *Spirifer trigonalis*, *Productus giganteus*, and *P. semireticulatus* are common fossils, and in some places the limestones are largely crinoidal, i.e. composed of the shelly plates which form the arms and stems of crinoids. These limestones are interbedded with a series of shales, sandstones, and coal-seams, several of the coals being immediately succeeded by a limestone, e.g. the Hurlet coal and limestone, as if there had been times when the shallow lagoons and swamps were suddenly submerged and occupied by marine organisms.

Edge Coal Group.—This is a shale and sandstone series, and it includes some valuable seams of coal, ironstone, and oil-shale, but no limestones. In Midlothian its thickness is about 800 feet. Some of the beds contain marine shells, others are full of terrestrial plants, showing that the gradual submergence which was in progress was now and then counterbalanced by the deposition of the sediment brought down in such quantity by rivers.

Upper Limestone Group.—This is about 600 feet in Midlothian; it contains three bands of limestone and four seams of coal, interstratified with sandstone, shale, and fireclay. The limestones contain the same fossils as those of the lower group, and though seldom more than three or four feet thick have been traced over an area of at least 1000 square miles, thus proving that the physical conditions of the period were very uniform over a large area.

In the western part of the area (Glasgow, Renfrew, and Arran) all these equivalents of the Yoredale Beds are much thinner, the Lower limestones being only 60 feet, the Edge Coal Group about 200, and the Upper limestones about 150 feet. All of them are found in Arran, where the red Corrie limestone is regarded as the equivalent of the Hurlet limestone of the mainland, for many of the beds are stained red in Arran.

7. Ireland

In no country can the rocks of the Carboniferous System be better studied than in Ireland. They occupy fully one-half of the superficial area of the country; the whole of the great central plain, which stretches completely across the island from east to west, consisting of Carboniferous limestones, though its surface is often covered by Pleistocene gravels (see map, Fig. 94). Here and there this limestone plain supports hills of low elevation composed of the Coal-measures, these outliers being the sole remnants of the beds which once spread over the limestone; their survival being due to the circumstance of their lying in synclinal basins.

For the sake of clearness and brevity the chief facts regarding the Avonian Series of Ireland will be given under three heads, (1) Northern counties, (2) The Great Central Plain, (3) Southern counties; the first and third of these areas each exhibiting a special and peculiar facies of the formation differing greatly from that of the central area.

Northern Counties.—The Carboniferous rocks of the more northern counties are merely an extension of the Scotch facies, but show a passage into the limestone facies as they are traced into

Leitrim and Sligo. In the counties of Derry and Tyrone a series similar to that of Arran and Ayrshire is found; the basement beds of red sandstone and conglomerate resting directly either on the Archæan schists or on the Lower Old Red Sandstone. The Tuedian or Calciferous sandstone is represented by about 2000 feet of strata, about half of which consists of reddish-brown sandstones, succeeded by calciferous sandstones and bands of shale which are well exposed in the valley of the Moyola River near Drapersdown. In these higher beds the commonest fossils are, *Leperditia Okeni*, *Modiola Macadami*, and *Protoschizodus axiniformis*, with *Dithyrocaris Colei*, *Cypris burdigalensis*, and remains of fish.

Above these beds, at Cullion and Desertmartin, limestones come in which are arenaceous in the lower beds and dolomitic in the higher; the prevalent fossils are corals (*Lithostrotion junceum*, *L. affinis*) and Brachiopods (*Productus giganteus* and *Orthis resupinata*).

Southwards the lowest beds appear to thin out, while higher beds come in above, so that in Fermanagh, Leitrim, and Sligo there is a more complete succession which, according to Messrs. Hull and Hardman, is as follows:—¹²

	Feet.
Black shales with some sandstones (Pendleside Beds)	600
Grey limestones with nodules of chert	500
Carbonaceous shales and sandstones (Calp)	1000
Lower limestones, grey and dark blue	600
Yellow sandstones and grey shales	200
Brown sandstones and conglomerates	500
	<hr/>
	3400

The basal beds are sometimes called Upper Old Red Sandstone, but they rest unconformably upon the Lower Old Red (see p. 237), and are now generally regarded as Lower Carboniferous because they seem to be the equivalents of similar beds in Derry and of the Lower Tuedian of Berwick.

Westward, in Sligo and Mayo, there is a similar succession, but the basal beds are absent and the lower limestones pass laterally into beds of calcareous breccia and conglomerate, indicating a shore-line. The upper limestone rises into hills with bold craggy escarpments, while the softer beds of the Calp have been eroded into broad vales.

Great Central Plain.—The central part of Ireland, from the shores of Dublin and Meath to Galway Bay and Lough Corrib, is a great tract of low undulating land which seldom rises to more than 300 feet above the sea. In consequence of this low elevation, the general horizontality of the limestones below it, and the prevalence of Pleistocene deposits, exposures are few in the central area, and

it is only in the outer parts, where the beds rise into hills, that the complete succession can be studied; the best sections are found on its western, eastern, and southern borders.

As the series above described is traced southward through Mayo and Roscommon into Galway it exhibits a change similar to that which takes place in England, namely a thinning of the sandstones and shales and a thickening of the limestones, till the series passes into a great limestone formation nearly 3000 feet thick, with the same black shales above and a still thicker set of basal sandstones. The following is the lithological succession in Galway and Clare according to Mr. Kinahan and the Survey:—

	Feet.
Upper limestone shales	80
Upper limestone { Limestone with layers of chert	1500
{ Black limestone and chert }	400
{ Upper cherty zone	
Lower limestone { The Fenestella limestone	300
{ Lower cherty zone	100
{ Shaly limestone	400
{ Lower limestone shale	150

About 3000

The zonal distribution of fossils in the limestone of Clare county has recently been ascertained by Mr. J. A. Douglas,¹³ and proves to be comparable with that in the Bristol sequence. He tabulates the beds and zones as follows:—

Survey Divisions.	Zones and Sub-zones.	Thickness.
Black Goniatite shales.	? = Pendleside Beds.	
<i>Upper Limestone</i> .—Bedded crinoidal limestones, both light and dark grey. Chert occurs in layers and nodules, some beds of oolitic limestone.	D ₃ <i>Cyathaxonia</i> . D ₂ <i>Lonsdaleia</i> . D ₁ <i>Dibunophyllum</i> θ. S ₂ <i>Productus cora</i> . S ₁ <i>Prod. semireticulatus</i> .	1900
<i>Lower Unstratified Limestone</i> .—Massive grey and mottled limestones, often dolomitic. Bryozoa abundant.	C. <i>Syringothyris cuspidata</i> .	450 to 1000
<i>Lower Stratified Limestone</i> .—Limestone with cherts at top, dark-grey or blue argillaceous limestones.	Z ₂ <i>Zaphrentis konincki</i> .	650
<i>Lower Limestone shales</i> .—Black shales and limestones, green and yellow sandstones.	Z ₂ <i>Spirifer clathratus</i> . ? <i>Cleistopora</i> zone. <i>Modiola</i> phase.	150

The basal yellow sandstones contain *Lamellibranchs* only. The succeeding shales have not yielded *Cleistopora*, but contain *Spiriferina octoplicata* and *Productus bassus*. The other zones contain assemblages which correspond closely with those of the South Wales and Bristol areas. A noteworthy feature is the great development of the *Dibunophyllum* and *Cyathaxonia* limestones, which have been termed the Burren limestone, from the district of that name, where they are magnificently exposed. It is thus described by Jukes¹⁴ :—

“A range of hills, rather more than 1000 feet in height, sweeps for about 20 miles along the south side of Galway Bay. They are formed entirely of bare rock from the sea-level to the hill-tops, the only soil being found in crevices of the rock, or in patches in the hollows of the valleys. This rock is all limestone, in regular beds, which dip gently to the south, at an angle of $1\frac{1}{2}$ degrees only ; and counting from the lowest bed that rises out on the sea-shore to the uppermost, which caps the summit of the hills three or four miles to the southward, there must be a thickness of at least 1600 to 1700 feet of solid limestone shown here.”

In Limerick and Tipperary there is a similar succession, and the limestone series attains a thickness of about 3500 feet, its thickest member being the *Fenestella* limestone (1500 to 1900 feet), while the upper (Burren) limestone has decreased to only 240 feet. The same succession of limestones can be followed eastward through Kilkenny and Carlow, and Fig. 93, across the Castlecomer coalfield, illustrates this part of the area.

East of Thomastown the limestones overlap the lower shales so as to rest directly on the granite of Carlow, and a little to the northward, in County Dublin, shales of the calp facies overlap the limestones, thus giving evidence of another shore-line.

This is confirmed by the sections on the coast of County Dublin near Lough Shinny and Rush, which have recently been examined by Dr. Matley¹⁵ and Dr. Vaughan. The lowest beds there seen are conglomerates and shales, indicating the close proximity of a coast-line, and these are overlain by limestones belonging to the *Dibunophyllum* zone. Still higher are limestones with *Cyathaxonia*, overlain by limestones and black shales with *Posidonomya Becheri*.

Southern Counties.—When the Carboniferous rocks are traced to the south-west through Cork and Kerry a still greater and much more sudden change takes place in the constitution of the system. This consists in the introduction of what appears to be a distinct group of shales and slates between the Yellow Sandstone and the Carboniferous limestone, and to which Sir R. Griffith gave the

name of *Carboniferous slate*. This group of beds has derived special importance from its bearing on the Devonian question, and the whole subject is so associated with the name of Jukes that it would be idle to attempt a better exposition of the interest attaching to the Carboniferous slate than is contained in Mr. Jukes's own description quoted below.¹⁰

"If we draw a parallel of latitude through the towns of Kenmare, Macroom, and Cork, the great development of Carboniferous slate lies wholly south of that line. If we examine the neighbourhood of the city of Cork itself, we find the [Upper] Old Red Sandstone with plants in its upper beds, and a very short distance above that we get solid Carboniferous limestone, with some black shales or slates between the two, but not more than 200 or 300 feet in thickness. Passing southwards to the mouth of the harbour of Monkstown or Queenstown, and then by Carrigaline and Coolmore, these intermediate black slates or shales thicken to 2000 or 3000 feet, still having the Old Red [or Coomhola Beds] below and the Carboniferous limestone above; but going still farther south by Ringabella to Kinsale, the dark-grey slates and grey grits thicken rapidly to 5000 or 6000 feet, and are nowhere covered by any part of the Carboniferous limestone, though they show here and there highly calcareous bands."

On Whiddy Island at the head of Bantry Bay there are black shales containing *Posidonomya Becheri* and *P. membranaceus*, the characteristic species of the shales above the limestone, and it is therefore highly probable that the Carboniferous slate is contemporaneous with the whole of the Carboniferous limestone, the lower and upper parts of that formation passing laterally into shales, just as its middle part does to the northward. We may therefore regard the Carboniferous slate as representing the whole of this limestone and its underlying shale, *i.e.* strata amounting to a thickness of 2600 feet in the northern part of Ireland; such, in fact, was Jukes's opinion.

8. Devon and Cornwall

This area has been left till the last, because the equivalents of the Avonian Series occurring therein are in many respects similar to those of the south of Ireland and are very different from the typical Avonian of the Bristol and Mendip area, in spite of the close proximity of the two facies.

Devonshire.—The delimitation of the Upper Devonian and Lower Carboniferous rocks in Devonshire has not yet been worked out. The junction-beds have not been specially described since

Mr. Salter compared them with those of Pembrokeshire in 1863,¹⁷ but his opinion was that the Pilton Beds included the equivalent of the lower limestone shale. He says, "Nearer Barnstaple these Pilton Beds begin to trough small patches of a barren softer slate which is only seen well developed south of Pilton and occupying the lower ground east and west of Barnstaple." In these soft slates the prevalent fossils are *Phillipsia seminifera*, *Spirifer bisulcatus*, *S. laminosus*, *S. cuspidatus*, *Productus Martini*, *Orthis Michelinii*, and other exclusively Carboniferous species.

Shales with a similar set of fossils occur at Fremington west of Barnstaple, and are succeeded by the Coddon Hill Beds consisting of shales and chert-beds; the shales yield the *Goniatites* characteristic of the lowest Pendleside Beds, *i.e.* *Prolecanites compressus*, *P. mixolobus*, and *Nomismoceras spirorbis*, and the cherts contain *Radiolaria*. They are overlain by black shales containing *Posidonomya Becheri*, and black limestones with the same fossil.¹⁸

The combined thickness of all these beds is not very great, apparently not more than 400 to 500 feet, unless a portion of the Pilton Beds is included, and it is impossible to regard them as representing the whole Avonian succession. From the fossils above quoted it looks as if the base and the upper portion of the normal sequence were present, and it is possible that the central beds are cut out by faulting, for the boundary of the Pilton Beds at and east of South Molton is believed to be a fault.

In South Devon and Cornwall nothing comparable with the Pilton or with the Fremington Beds has yet been found. The lowest Carboniferous Beds are either unconformable to or faulted against the highest Devonian rocks; but the cherts and limestones of the Coddon Hill Group are well developed and appear to be rather thicker than in North Devon. West of Dartmoor they are associated with lava-flows, and the general succession according to Mr. Reid is as follows:—¹⁹

	Feet.
Upper lava of Brent Tor, etc.	about 150
Beds of Radiolarian chert	70
Black shales and lenticular limestones	250
Lower lavas	50
Hard black shale and chert-beds	150

I have elsewhere²⁰ suggested that the break which here seems to exist between the Devonian and Carboniferous Systems may be a result of the volcanic action indicated by the presence of the lavas and by the intrusive mass of Brent Tor, which is supposed to have been a volcanic vent. The sea-floor may have been slowly raised

CORRELATION TABLE OF AVONIAN SERIES

Bristol.	North Wales.	Lancashire.	Durham and Northumberland.	Scotland.	Ireland (Clare).			
D ₇ Sandstones.	Pendleside Beds.	Pendleside Beds, shales and limestone.	Yoredale Beds.	Limestones and shales.	D ₇ Black Shales.			
D ₂ Shales and limestones.	Limestones.	Limestones.	Limestones, sandstones, and shales.	} Oil-shale Group.	D ₃ Limestones.			
D ₁ Limestones.	Limestones.	Limestones.	Carbonaceous Group.		D ₂ Limestones.			
S ₂ Limestones.	Limestone and Red Sandstone.	Limestones.	Upper Tued-ian or Fell Sandstone Group.	Granton and Hailes sandstones.	D ₁ Limestones.			
S ₁ Limestones.	Limestone and shales. Conglomerate.	Limestone and shales. Conglomerate.	Lower Tued-ian or Cement-stone Group.	Cement-stone Group.	S ₂ Limestones.			
C Limestones.					S ₁ Limestones.			
Z Limestones.	} Conglomerate.				C Limestones.			
K Shales.					Z Limestone and shale.			
				Shales.	K Sandy shale and sandstone.			

or bulged upward by the rising mass of lava till several submarine vents were established, and during such a movement little deposition would take place. The probability of this view is increased by a comparison of the Cornish sequence with that of Brittany, where a thick volcanic series is overlain by shales that are probably of Viséan and possibly of Yoredale age.

C. CONTINENTAL REPRESENTATIVES

1. *France and Belgium*

Two very different facies of the Avonian Series are found in the north of France; quite as different as those of Gloucestershire and Devonshire in England, the one being essentially calcareous and the other argillaceous. The former is only found in the north-east of France and in Belgium, the latter occurring in Brittany, Sarthe, and the Loire valley, and round the borders of the Central Plateau. It will be desirable to take the former first since the succession is complete and comparable with that of the Bristol area.

Belgium and N.E. France.—The Carboniferous rocks of this district lie in a set of deep and narrow troughs which succeed one another along a line extending from the Boulonnais on the west by Bethune, Tournai, Mons, Namur, and Liège. French and Belgian geologists use the term *Dinantian* for this part of the Carboniferous System, but as defined by them its limits are not quite coextensive with the Avonian either at the bottom or the top. They also divide it into two stages, the Tournaisian and the Viséan, names taken from the towns of Tournai and Visé. The most complete section of the series is that exposed in the valley of the Meuse by Hastière, Waulsort, Dinant, and Yvoir, and the succession is repeated in the basin of Namur to the north, at the junction of the Meuse and the Sambre. Visé lies much farther down the valley of the Meuse to the north-east of Liège, and the whole of the Visé limestone has been found to belong to the highest Avonian zone, that of *Dibunophyllum*, and to be similar in character to that of Derbyshire; moreover, it is said to rest unconformably on the Devonian, so that it is not a complete development of the so-called Viséan stage.

The most recent descriptions of the Belgian Series are those by Professor de Dordolot, Dr. G. Delépine, and Dr. Vaughan. The following is a brief summary of the faunal sequence as determined by Dr. Vaughan and Dr. Delépine in a joint visit to the Belgian area.²¹ The normal succession is :—

Viséan, about 1200 feet	Dark shales with, locally, a Pendleside fauna.	
	Limestone with <i>Productus longispinus</i> and, locally, <i>Dibunophyllum</i> and <i>Lonsdaleia</i>	} = D ₂
	Pseudo-breccia with <i>Productus undiferus</i>	= D ₁
	Limestone with <i>Lithostrotion</i> and <i>Seminula ficoides</i>	= S ₂
	Shallow-water limestone with <i>Productus θ</i> and <i>Caninia bristolensis</i>	} = S ₁
Tournaisian, about 600 feet	White oolite with <i>Productus sublævis</i> and <i>Cyathophyllum φ</i>	= C ₂
	Limestones of Paire and Yvoir with <i>Spirifer</i> <i>Konincki</i> , <i>Caninia patula</i> , and <i>Caninia cylindrica</i>	} = C ₁
	Limestones and shales ("Calc-schistes") with <i>Zaphrentis</i> and <i>Spirifer clathratus</i> (= <i>S. tornacensis</i>)	} = Z
	Shales with <i>Spiriferina peracuta</i> and <i>Zaphrentis</i> <i>Vaughani</i>	} = Z
	Calc-grits and shales with <i>Eumetria</i> , <i>Camarotoechia</i> , and Ostracods; the Upper Famennian of Belgian authors	= K

West of the Meuse in the Dinant area C₁ and C₂ take on a "knoll" character and are termed Waulsortian; the rocks are massive mottled limestones with abundant Fenestellids. In these beds characteristic fossils are: *Spirifer princeps*, *S. pinguis*, *Productus plicatilis*, and *Amplexus coralloides*. East of the Meuse in the Dinant area there is no Waulsortian phase; the black marble of Dinant ("Marbre noir") belongs, probably, to C₂. In the Namur basin a large part of the series (Z to C₂) is dolomitised ("Grande Dolomie"). At Visé only Dibunophyllum Beds occur, and these are of the upper knoll type.

This calcareous facies of the Dinantian can be traced eastward by Liège to Limbourg (Aix la Chapelle), but when it reaches the Rhine the limestones are partly replaced by shales, and what we know as the Pendleside fauna extends downward through a greater thickness of beds. The succession near Dusseldorf is:—

	Feet.
Shales with <i>Posidonomya Becheri</i>	? 1000
Limestones with a Viséan fauna	300
Shales with <i>Spirifer clathratus</i> (= <i>S. tornacensis</i>).	1500

Brittany and Basse Loire.—The Avonian Series of Brittany commences with a volcanic group which is believed to have a thickness of more than 1500 feet in the west, consisting of conglomerates and felspathic tuffs with thick masses of andesite; but these beds only occur on the northern side of the basins of Chateaulin and Laval. The conglomerates rest unconformably on older rocks from Devonian to Cambrian, and as they contain no marine fossils their zonal age is unknown.

Above them in the Chateaulin basin is a great thickness of unfossiliferous black shales with layers of felspathic sandstone,

probably 3000 feet thick, and a few fossils (*Phillipsia* and *Productus*) have been found in lenticles of limestone near the top. In the basin of Laval there is a more massive black limestone containing *Productus giganteus* and other Viséan species, overlain by shales, coal-seams, and sandstones with plant remains (*Bornia transitionis*, etc.), and in the centre of the basin is a band of red and green limestone.

Only the plant-bearing beds pass into the basin of Ancenis and the Basse Loire district, but these are more than 3000 feet thick, consisting of shales and sandstones with many beds of anthracitic coal. The plants are those mentioned on p. 245.

From the above account it will be seen that the Tournaisian does not appear to be represented, except perhaps by conglomerates and lavas. The greater part of the series belongs to the Viséan, and the place of the Yoredale Beds is taken by a group of lagunic and estuarine deposits.

2. Germany

East of the Rhine in Germany a very different facies prevails, which has long been known as that of the Culm. This consists of a thick series of shales and sandstones; limestones only occurring as lenticular beds or as layers of calcareous nodules. The series is generally divided into a lower and an upper group, the lower being essentially marine, while the higher seldom contains anything but plant remains. In Westphalia, Hesse, and Nassau the Lower Culm has at the base chert-beds and siliceous limestones about 200 feet thick, containing *Prolecanites compressus*, *Pronorites cyclolobus*, and *Orthoceras striolatum*; the overlying beds are dark thin-bedded limestones containing *Glyphioceras sphaericum* and *G. crenistria*, with *Productus giganteus* and *Chonetes papillionaceus*. Above this are shales abounding in *Posidonomya Becheri*, and the total thickness is about 1400 feet. The Upper Culm consists of coarser sandstones, often pebbly, and contains the characteristic plants, *Knorria imbricata*, *Bornia transitionis*, *Lepidodendron veltheimianum*.

This Culm facies is found also in the Harz Mountains, Thuringia, the Fichtelgebirge, and over a large area in Saxony. It likewise occupies parts of Silesia and Moravia, where it is of great thickness and has a somewhat different facies. According to Stur, the Silesian succession is as follows:—

Shales with plant remains.

Sandstones and shales with *Posidonomya Becheri*, *Glyphioceras sphaericum*, etc., and other beds with plants.

Sandstones, shales, and conglomerates with both marine and terrestrial fossils.

Carboniferous deposits of the Culm type are also found in the south-west of Germany, in the Black Forest and in the Vosges district, with which the tracts in Central France were probably continuous.

3. South of France, Pyrenees, and Spain

When we pass into Southern France we enter a region where still another facies prevails. As a type of this the succession found in the Montagne Noire, near Corbières, may be taken. As described by M. Bergeron this is :—

Grey limestone with *Productus giganteus*.
 Sandstones with plants (*Lepidodendron veltheimianum*).
 Shales with *Spirifer tornacensis* and *Posidonomya Becheri*.
 Radiolarian chert-beds with phosphatic nodules (*Glyphioceras diadema*),
 succeeding Upper Devonian.

A similar succession is found at intervals all along the chain of the Pyrenees, with the addition at the base of compact limestones (the "marbres griottes"), variegated with red and brown, which contain *Glyphioceras crenistria*, *Pronorites cyclolobus*, and *Prolecanites Henslowi*. Still farther west in Asturia Professor Barrois has described the following sequence :—²²

	Feet.
Shales and limestones of Lena, with <i>Amplexus coralloides</i> , <i>Lonsdaleia floriformis</i> , and <i>Fusulina</i>	240
The Cañon limestones with few fossils, <i>Poteriocrinus crassus</i> , <i>Prod. aculeatus</i> , <i>Spirifer striatus</i>	700
"Marbres griottes" with the <i>Goniatites</i> above mentioned	60

It is curious to find limestones with what we regard as Pendleside species of *Goniatitidæ* here conformably succeeding the Upper Devonian ; but there is no doubt about the sequence, and we may regard these forms as southern species which did not find conditions suitable to them in the north-west of Europe until a late date in Dinantian time.

4. Russia

In this region the Lower Carboniferous Series is a combination of the Culm and the Dinantian limestone facies. The beds lie for the most part horizontally and are exposed in three large areas, that of Donetz in the south, the Moscow basin in the centre, and on the slopes of the Ural Mountains to the east. Ignoring local variations the general sequence in the Ural and Moscow areas is :—

3. Limestones with *Prod. giganteus*.
2. Sandstones, shales, and coal-seams ; some of the beds yield *Prod. giganteus*.
1. Sandstones and shales with lenticular limestones containing *Prod. mesolobus*.

These beds are from 5000 to 6000 feet thick and appear to represent both the Tournaisian and Viséan stages. In the Donetz area, according to Tschernyschew, nearly the whole series consists of limestones.

D. CONDITIONS OF DEPOSITION

The geographical conditions which prevailed in the British area during Avonian time are fully discussed in my *Building of the British Isles* (3rd ed., 1911), but it will be useful here to extend our view to those parts of the European region which have been briefly mentioned in the preceding pages.

The complete absence of any trace of Carboniferous strata in Norway, Sweden, Lapland, and Finland seems to indicate the existence of land over a large part of Northern Europe during this period. This inference is confirmed by the character of the deposits found in Northumberland, Scotland, and the north-east of Ireland ; these being mainly detrital deposits carried down by rivers and such as would be accumulated in a large bay or gulf. Hence we conclude that the Scandinavian land extended westward across the North Sea and across the north of Scotland into the North Atlantic region.

Again on the eastern side we find a broad band of Carboniferous strata in Russia extending from the Valdai Hills, south-east of St. Petersburg, northwards by the south end of Lake Onega. In this band the lowest beds are terrigenous deposits similar to those of Scotland, and here again, therefore, we are on the borders of continental land.

With regard to the southern border of the Scandinavian land there is less certainty, because all evidences of it are buried and concealed beneath the Neozoic deposits of the Germanic region. Probably, however, the coast-line passed across the southern part of the North Sea and across Denmark into the Baltic basin, whence it must have curved north-eastward through the Baltic provinces of Russia. Here it may be pointed out that the absence of Avonian deposits in Poland is no proof that this country was land at this time. The Carboniferous deposits may have been largely removed from that area before Permian time, and seeing the great thickness which they have in Silesia and as far east as Cracow, it would be

surprising if they had not extended for some distance to the north of these places.

Passing now to the Atlantic region there is reason to think that a large part of this was also occupied by land, and that a part of its coast-line passed through the extreme north-west of Ireland. Again, the great thickness of shale in the south-west of Ireland and the north-west of France indicates the neighbourhood of land and the debouchures of large rivers which carried much sediment derived from such land. We may therefore picture a continent which almost encircled the British area, lying not only to the north but also to the west and south-west of it; and indeed it seems probable that a promontory of this land actually occupied parts of Cornwall, Brittany, and the intervening channel area during the Tournaisian epoch.

Another tract of land which was probably connected with the Atlantic continent seems to have stretched across Central France, for in the basin of the Loire the Dinantian (=Avonian) deposits are entirely of terrigenous origin, and are probably all of Viséan and Namurian age, while to the southward in La Vendée even these are absent, and small tracts of Westphalian Coal-measures rest directly on Archæan rocks. We have seen also that when Dinantian Beds come in again to the southward in Asturia, the Pyrenees, and the Montagne Noire they are of quite a different facies, hence the land above indicated seems to have separated a southern from a northern Carboniferous Sea.

From Central France this land may have extended across the valley of the Rhone between Lyons and the Vaucluse, and thence through the Western Alps and Northern Italy, where no traces of Dinantian strata have yet been found. Land also existed at this time over a certain area to the north of Metz and Sarrebruck, for near the latter place Coal-measures rest directly on the Lower Devonian, but this may have been only a large island.

The limestone facies of the Avonian Series must have been formed in those parts of the Carboniferous Sea which were not subject to the incursion of currents setting off the surrounding land. It must originally have extended continuously from the west of Ireland, all round an island which existed in Viséan time over St. George's Channel, Central Wales, and Central England—an island which I have elsewhere called "St. George's Land." Thence these limestones probably extended broadly into the north-east of France and through Belgium into Prussia, nearly as far as the Rhine.

There is no valid reason for imagining any special contraction of the sea space on the Franco-Belgian border, as suggested long ago by Professor Gosselet, and still supported by some French geologists.

The trough-like syncline in which the limestones lie is a feature produced by subsequent flexuring; there is no indication of a shore-line either along the northern or the southern line of outcrop, and we have only to prolong the dip of these limestones to see that they must have extended indefinitely both to the northward and to the southward. Who will deny that there may be another syncline under Holland, and that Carboniferous limestone may occur in it?

From the distribution of the limestones, as above indicated, we may infer that no large rivers entered that portion of the Avonian sea which is now Central Ireland, and also that the island tract of St. George's Land had then a dry climate and was without streams of any size. At the same time there is no ground for supposing that the limestones formed around this island were of the nature of coral-reefs. Crinoids and molluscan shells are the predominant constituents of these limestones as they are of the Devonian limestones (see p. 206), and the corals are distributed through the limestones over wide areas, not concentrated in reef-like masses round the shores of the island.

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CHAPTER X

THE CARBONIFEROUS SYSTEM (*continued*)

II. WESTPHALIAN SERIES

A. SUBDIVISIONS AND GENERAL RELATIONS

As explained on p. 245 the second of the three great series of strata into which the Carboniferous System is now divided has received the name of *Westphalian*, and to it belong all the beds which have been classed as "Upper Carboniferous" in the British Isles. These generally occur in conformable succession to the Avonian Series, but they often extend beyond the limits of the older series, and come to rest on Silurian or other more ancient rocks. Moreover, even when they overlie the Avonian there are sometimes evidences of a slight break between the two series, and there is always a change in the species of plants above this horizon.

In the British Isles the "Coal-Measure" Series is generally underlain by a set of massive sandstones which are known collectively as the Millstone grit, but this is a very variable group, being sometimes over 3000 feet thick, and sometimes only represented by 300 or 400 feet of sandstone and shale. In the areas where the Coal-measures are most fully developed they reach a thickness of 6000 to 7000 feet, and have been divided into Lower, Middle, and Upper stages. On this basis, therefore, the Westphalian Series is divisible into four stages, and has a maximum thickness of about 10,000 feet.

A more scientific division of the series is one based on the different assemblages of plants that are found in this great succession of strata, and by a study of these Dr. Kidston has recognised three different assemblages,¹ though the two higher blend into one another through a set of "Transition Beds." The particular differences in these plant-assemblances will be mentioned

on a later page. The correlation of the two sets of stages is given below.

Upper Coal-measures	with Fourth flora.
Transition Coal-measures	„ Third flora.
Middle Coal-measures	„ Second flora.
Lower Coal-measures	} „ First flora.
Millstone grits	

B. LIFE OF THE PERIOD

1. *The Fossil Flora*

a. Equisetales.—*Calamites* were gigantic Equiseta or horse-tails, and consisted of a large hollow pith cavity encased in a thin cylinder of woody tissue. The central part has generally been filled up with mineral matter, forming the casts which are such common Carboniferous fossils. The outer ligneous envelope, being carbonised and friable, is seldom preserved in a perfect state.

The name *Calamites* is at present restricted to these jointed stems, while other names, *Asterophyllites* and *Annularia*, are given to different varieties of foliage which belonged to *Calamites*. The fruit is a scaly spike (*Calamostachys* and *Palæostachya*), in which sporangia are arranged like those of Equisetum.

Sphenophyllum is the foliage of a plant related to *Calamites*, but is now known to differ in several respects, and the fruit is a whorled sporophyll resembling that of the recent genus *Psilotum*.

Calamodendra are casts of the central cavity or pith of plants resembling *Calamites*, but having a thick woody outer coating or bark. *Calamodendron* thus appears to have been a highly developed Equisetum.

b. Lycopodiales.—*Lepidodendra* were gigantic members of the Lycopodiales, or Club-moss family, having trunks many feet in girth and 40 to 60 feet in height. The trunks branch toward the top into several limbs, which divide again into smaller boughs. The foliage consists of simple linear leaves, which are sometimes found attached to the terminal branches (Fig. 96), and the angular scars on the stem are the marks left by the detachment of these leaves. *Ulodendron*, *Lepidophloios*, and *Halonias* are allied genera.

The scaly cylindrical bodies which are known as *Lepidostrobi* are the cones which contain the sporangia or seed-cases of the *Lepidodendra*, and were borne at the extremities of some of the branches.

Sigillaria.—These appear to have been the commonest trees in the swampy portions of the Carboniferous forests, and have evidently supplied the chief mass of the material which forms our

Fig. 95.—GROUP OF COAL-MEASURE PLANTS.

1. <i>Sphenopteris linearis</i> .	3. <i>Odontopteris Schlotheimi</i> .
2. <i>Sphenopteris affinis</i> .	4. <i>Neuropteris acuminata</i> .
5. <i>Calamites</i> (restored and $\frac{1}{4}$ th of natural size).	

coal-seams, while their roots (*Stigmariæ*) ramify in the under-clays beneath. They were tall trees, branching at the top, and rivalling the *Lepidodendra* in height, with a bare trunk fluted longitudinally, and regularly ornamented by the pits or scars left at the points where the leaf-stalks were attached. These leaves were long and narrow, and similar to those of *Lepidodendron*. The fruit consists of small sporangia borne at the basis of slightly modified leaves; *Sigillaria* was therefore a Lycopod, and allied to *Lepidodendron*.

Fig. 96.—GROUP OF COAL-MEASURE PLANTS.

a. *Calamites cannaeformis* (root end).

b. *Alethopteris lonchitica*.

c. *Sigillaria reniformis*.

d. *Lepidodendron Sternbergi*.

e. *Stigmaria ficoides*.

Stigmariæ.—The roots of *Sigillaria*, *Lepidodendron*, and *Bothrodendron* are so much alike that it is impossible to distinguish them. Consequently they are all known as *Stigmaria*, long, branching, and tapering, with numerous rootlets spreading out in all directions; such roots have been found which were upwards of 20 feet in length. Perhaps, like those of the modern mangrove-tree, these roots were partly aerial, rising well above the low-water

mark of the swamp, and uniting in a dome-shaped manner to support the trunk.

c. **Pteridosperms** and **Primofilices**.—Fern-like fronds are abundant in the Coal-measures, and the roofs of coal-seams are sometimes covered with beautiful impressions of such fronds. Until recently these were regarded as true ferns, but it has been

Fig. 97.—*LEPIDODENDRON ELEGANS* (BROUGH).

1. A terminal branch.

2. Leaf-scars from the stem.

found that many of them belong to plants which developed true seeds and not spores like those of existing ferns. They are now regarded as a distinct group of plants, intermediate between ferns and Gymnosperms, and are known as *Pteridosperms*.

True ferns of an ancient type (*Primofilices*) are also represented among these leaves, for some have been found bearing sporangia, and stems with leaf-scars like those of modern tree-ferns also occur (*Psaronius*). Fructiferous fronds, however, are rare, and it is

impossible to distinguish the sterile fronds of these ferns from those of the Pteridosperms; thus some of the fronds known as *Pecopteris* and *Sphenopteris* belong to one group and some to the other, so that these names only stand for certain forms of sterile fronds which are similar in their venation and general characters.

In the present state of our knowledge, these names have still to be used generically, and some of the commonest frond-forms thus designated are—*Alethopteris* (Fig. 96, *b*), *Neuropteris* (Fig. 95, 4), *Odontopteris* (Fig. 95, 3), *Pecopteris*, *Cardiopteris*, *Linopteris*, *Mariopteris*, and *Sphenopteris* (Fig. 95, 1 and 2).

The seeds of the Pteridosperms have long been known under the names of *Lagenostoma*, *Trigonocarpus*, *Rhabdocarpus*, etc.

Cordaitales.—The stems of plants in some respects resembling the true Coniferæ (*Pitys* and *Dadoxylon*) have also been met with, especially in the volcanic tufts of the Scotch Carboniferous Series. The lower slopes of the old volcanoes were doubtless clothed with these trees, their habitat being in such high and dry localities, and not in the swampy ground where the other plants flourished. In the structure of their stems these plants show affinities to the Pteridosperms as well as to the Coniferæ.

Cordaites was a remarkable plant placed by most botanists in a distinct phylum, but by some with the conifers. The stem grew to a height of 20 or 30 feet, and carried a number of long sword-shaped leaves with parallel venation, something like those of a yucca. The leaves were attached by broad bases and left large leaf-scars on the stem when they fell off. The tree bore bunches or spikes of fruit (*Antholites*) with seeds somewhat resembling the fruits of a yew, but more heart-shaped, and these are known as *Cardiocarpus*.

Some of the plants above mentioned are more abundant in the lower part of the series and some in the higher parts. A study of their distribution has enabled Dr. Kidston¹ to recognise four successive assemblages of plants in British Coal-measures, and Zeiller has found the equivalents of all but the uppermost in those of the continent. The principal features of these assemblages are given below.

Plants of the Millstone Grit and Lower Coal-Measures

Lepidodendra are abundant; *Sigillaria* not very common. *Calamites* are represented by *C. Suckovi* and *C. ramosus*. The prevalent fern forms are *Alethopteris* and *Sphenopteris*; common species of the first being *A. lonchitica* and *A. decurrens*, of the second *S. obtusiloba*.

Plants of the Middle Stage

In this stage *Sigillaria* is more abundant than *Lepidodendron*, *S. elongata*, *S. polyploca*, and *S. Brardii* being common species. *Calamites* and *Sphenophyllum* are also very abundant, though no species is restricted to this division. Fern-like fronds abound, *Sphenopteris* and *Neuropteris* reaching their maximum development. Of the former *S. (Zeillaria) delicatula*, *S. (Corynepteres) coralloides* are characteristic species.

Plants of the Transition Stage

These are a mixture of typical middle stage forms, such as *Pecopteris Miltoni*, *Annularia radiata*, *Sphenophyllum cuneifolium*, and *Alethopteris lonchitica*, with species characteristic of the Upper stage, such as *Alethopteris Serli*, *Neuropteris rarinervis*, and *Sphenophyllum emarginatum*.

Plants of the Upper Stage

In these beds *Calamites* become rare, *Lepidodendron* is not common, and *Sigillaria* also less abundant. The most abundant plants are fronds of the *Pecopteris* form, such as *P. arborescens*, *P. oreopteridea*, *P. polymorpha*, and *P. cyathea*, but some forms of *Neuropteris* (*N. rarinervis*, *N. macrophylla*, and *N. ovata*) are common. *Alethopteris Serli* and *Cordaites angulosostriatus* are also typical Upper Coal-measure species.

2. *The Land and Freshwater Fauna*

a. **Mollusca.**—In the Coal-measure shales, and associated with many of the plants above mentioned, shells somewhat resembling the recent *Unio* are frequently found. They have been referred chiefly to three genera, *Carbonicola* (= *Anthracosia*), *Anthracomya*, and *Naiadites*, and their affinities have recently been studied by Dr. W. Hind, who refers the first two genera to the *Unionidae* and the third to the *Mytilidae*, but believes that all of them were freshwater forms. He remarks that their occasional or rare association with marine shells is no proof that they were capable of living in salt water, for their shells may have been carried down by rivers into bays and estuaries.

b. **Arthropoda.**—True Insects, Myriapods and Arachnids, have also been found in the Coal-measures, including crickets, beetles, and a scorpion. Crustacea also inhabited the waters, the small Ostracoda—*Bairdia*, *Leperditia*, and *Beyrichia*, and the Phyllopod

Estheria—swarming in some localities. Several species of Xiphosura allied to the modern *Limulus* (king-crab) have been described by Dr. Woodward, and referred to the genera *Prestwichia* and *Belinurus*. There were also a few Eurypterids, this being their last appearance in England.

c. **Fishes.**—Fish remains, of Crossopterygian and Elasmobranch genera, are everywhere abundant, but it is difficult to separate entirely the freshwater forms from the marine, because some (like the Mollusca) seem to have been equally at home in salt and brackish water; some of them, like the modern salmon, may have lived in the sea at certain seasons, and in the estuaries and rivers during other parts of the year. The following genera are, however, most frequently associated with the Coal-measure plants:—*Celacanthus*, *Cheirodus*, *Ctenacanthus*, *Ctenoptychius*, *Gyracanthus*, *Megalichthys*, *Platysomus*, *Pleuracanthus*, *Rhizodus*, *Rhizodopsis*, and *Strepsodus*.

d. **Amphibia.**—Thirteen genera of Labyrinthodonts are recorded from British Carboniferous rocks, *Anthracosaurus*, *Loxomma*, *Ophiderpeton*, *Urocordylus*, etc., mostly from the Jarrow coalfield in Leinster, Ireland. Others (*Archegosaurus*) occur in Prussia and (*Baphetes*, *Dendrerpeton*) in Nova Scotia. Footprints have also been observed in the Forest of Dean coalfield and in the limestone series of Dalkeith, Scotland. The larger of these Amphibians are believed to have measured 7 or 8 feet in length, but others were very small; they were probably fluviatile creatures preying on the fish and Crustacea which swarmed in the swamps and lagoons of the period.

3. The Marine Fauna

The Millstone grits are probably marine deposits, for land plants are not common in them, and the intercalated shales sometimes contain marine species of Mollusca as well as fish remains. The Lower Coal-measures were swamp deposits formed along the fringe of sinking land areas, parts of which were from time to time invaded by the sea. Hence marine fossils are found in them at certain horizons. The species which have been found in these beds in Britain and also at two horizons in the Middle Coal-measures of Staffordshire are tabulated on p. 293. The first two columns show how many of the species range up from the higher parts of the Avonian Series.

C. WESTPHALIAN SERIES IN BRITAIN

Just as the Lower Carboniferous Series is in most places brought to the surface along tracts of anticlinal flexure, so the Upper Series

	From Carb. L.	Pendle Group.	Millst. grit.	Lower C.M.	Middle C.M.
Goniatites (Gastrioceras) carbonarius, <i>v. Buch.</i>		x	x	x	
" " Listeri, <i>Martin</i>		x	x	x	
" (Glyphioceras) bilinguis, <i>Salter</i>		x	x	x	
" " diadema, <i>Beys.</i>		x	x		
" " reticulatus, <i>Phil.</i>		x	x	x	
" " spiralis, <i>Phil.</i>			x		
Coelonautilus falcatus, <i>Sow.</i>				x	x
Pleuronautilus quadratus, <i>Flem.</i>	x				x
" costatus				x	
Temnocheilus carbonarius, <i>Foord</i>					x
" concavus, <i>Sow.</i>					x
Ephippioceras clitellarium, <i>Sow.</i>		x		x	x
Orthoceras Steinhaueri, <i>Phil.</i>	x	x	x	x	
Euomphalus tuberculatus, <i>Flem.</i>					x
Pleurotomaria monilifera, <i>Phil.</i>	x	x	x		
Macrocheilus michotianus, <i>de Kon.</i>					x
Bellerophon hiuleus, <i>Sow.</i>		x	x	x	x
" Urei, <i>Flem.</i>	x	x	x	x	
Nucula æqualis, <i>Sow.</i>		x	x	x	x
" gibbosa, <i>Flem.</i>		x	x	x	x
Leda stilla, <i>M'Coy</i>	x		x	x	
" acuta, <i>Sow.</i>					x
Ctenodonta lævirostris, <i>Portl.</i>	x	x	x		x
Myalina Flemingi, <i>M'Coy</i>			x		
" peralata, <i>de Kon.</i>	x	x	x		
" Verneuilli, <i>M'Coy</i>	x		x		
Schizodus antiquus, <i>Hind</i>		x	x		
" carbonarius, <i>Sow.</i>				x	
" axiniformis, <i>Sow.</i>	x	x		x	
Sedgwickia attenuata, <i>M'Coy</i>			x		
Sanguinolites ovalis, <i>Hind</i>			x		
Edmondia accipiens, <i>Sow.</i>					x
" senilis, <i>Phil.</i>	x	x			x
Posidoniella lævis, <i>Brown</i>		x	x	x	
" minor, <i>Brown</i>		x	x	x	
" semisulcata, <i>Hind</i>			x		
Pseudamusium fibrillosus, <i>Salter</i>		x			x
Aviculopecten gentilis, <i>Hind</i>			x		x
Lciopteria longirostris, <i>Hind</i>		x			x
Pterinopecten papyraceus, <i>Goldf.</i>			x	x	x
" carbonarius, <i>Hind</i>		x		x	x
Productus semireticulatus, <i>Martin</i>	x	x	x	x	x
" scabriculus, <i>Martin</i>		x	x	x	x
Chonetes laquessiana, <i>de Kon.</i>	x	x	x	x	x
Spirifer bisulcatus, <i>Sow.</i>	x	x	x	x	
" Urei, <i>Flem.</i>		x	x	x	x
Discina nitida, <i>Phil.</i>	x	x	x	x	x
Lingula mytiloides, <i>Sow.</i>	x	x	x	x	x
" squamiformis, <i>Phil.</i>	x			x	x

is generally found in synclinal troughs or basins, the highest portion of the series usually lying in the central parts of such basins. All areas where workable coals exist are called *coalfields*.

Of such coalfields there are no fewer than eighteen in England and Wales, some large and some very small, and if the unproductive Devonshire basin is included there are nineteen. In Scotland there are three coalfields in which Westphalian measures are worked, besides three others in the underlying Avonian Series. In Ireland there are five such basins.

In describing the Coal-measures found in these numerous basins it will be convenient to group them into natural areas wherein a similar succession of strata is found, and as their most complete development is exhibited in the basins which lie on each side of the Pennine Anticline (see Fig. 86), these will be placed first. The areas may therefore be taken in the following order :—

1. The South Pennine and Midland area.
2. The Newcastle Coalfield.
3. Scotland.
4. Ireland.
5. Bristol, Somerset, and South Wales Coalfields.
6. Devonshire.

1. *The South Pennine and Midland Area*

This area will include the Nottingham and Yorkshire coalfield on the east and those of Lancashire and North Staffordshire on the west, the latter probably being connected under the Cheshire basin with the Flint and Denbigh coalfield (see Fig. 98, and the map, Fig. 87). We shall also include the other Midland coalfields to the southward, those of Shropshire, South Stafford, Leicestershire, and Warwickshire, since they are all portions of a series of deposits which originally formed one continuous sheet.

In the basins which flank each side of the Pennine range the complete succession is as follows :—

		Feet.
Upper C.M.	{ Red and purple sandstones and marls with thin limestones	about 700
Transition C.M.	{ Grey sandstones and shales, red and purple marls ; some thin coal-seams . .	„ 1500
Middle C.M.	{ Grey shales and sandstones with many seams of coal and ironstone	„ 2500
Lower C.M.	{ Grey flagstones and black shales with some coal-seams (generally thin) . . .	1000 to 2500
Millstone Grit	{ Sandstones and shales, thickening toward the north-east	400 to 3500
		<hr/> 9500

The **Millstone Grit** consists of several sets of grits and flagstones separated by shales of varying thickness. Its thickness increases to the northward, and finds its maximum in East Lancashire and the adjacent part of Yorkshire, where it is said to be over 3500 feet thick. Throughout the northern part of the area the following subdivisions can be traced, though the thickness of each varies greatly :—

First grit or rough rock.
Shales.
Second grit.
Shales.
Third or Chatsworth grit.
Shales.
Kinderscout grit, or fourth grit.

The lowest grit takes its name from the high tableland of Kinderscout in the Peak country, which consists of this rock and rises to a height of 2000 feet above the sea. The third grit forms long conspicuous escarpments on both sides of the central area. The second grit is less persistent than the others, or rather the shales above thin out so that it coalesces with the first grit. The Rough Rock is a very coarse grit, sometimes passing into a conglomerate of small quartz pebbles. In Lancashire it contains a workable coal-seam called the "Feather-edge coal." The shales below also include thin seams of coal. To the south-west in Staffordshire the middle grits thin out, but the fourth grit appears to be represented on Congleton Edge by a set of grits and shales about 500 feet below the third grit, so that the group here is not less than 1000 feet thick, and has the Pendleside shales below it.

Still farther south the grits thin out entirely, and they do not appear in the South Staffordshire or Warwickshire coalfields. In Nottingham also they thin southward and have nearly disappeared at Ashby de la Zouch, in Leicestershire, where only 50 feet of such grit is left at the base of the series. A similar small tongue of grit reaches to the Wellington district of Shropshire and then thins out.

Lower Coal-Measures.—These are sometimes called the Gannister measures, *gannister* being the miners' name for a peculiar hard and compact siliceous underclay (or fireclay) which often forms the floors of the coal-seams. Hard grey flagstones are the predominating beds in this division, with subordinate bands of shale. The coals are generally thin, but two or three from 3 to 4 feet thick are often worked. In the vicinity of the coal-seams plant remains are abundant, but the fossils in the other beds are generally marine forms (see p. 293).

Fig. 98.—SECTION ACROSS THE CHESHIRE BASIN FROM NEAR WREXHAM IN DENBIGH TO ENDON IN STAFFORDSHIRE. Distance 42 miles. Reduced from section by Sir A. Ramsay, prepared for the Coal Commission Report.

In North Staffordshire these measures are 2400 feet thick if the top of them is taken at the marine band above the Mansfield coal, but Dr. Kidston is inclined to place it at the Ash coal, still higher up. They are probably quite as thick in Lancashire if the same horizon is taken as the line of division. In Flint they are considered to be about 1000 feet thick and 1800 feet at Wigan, in Lancashire, where they are well exposed in the cuttings of the Wigan and Liverpool railway. *Carbonicola acuta*, *C. robusta*, and *C. turgida* are common in these measures.

On the eastern side of the area there is a similar development of Lower Coal-measures, but the thicknesses assignable to them depend upon the horizon which is taken to be their upper limit. In Nottingham and Leicester they are said to be about 1000 feet thick, but when the series recurs in Warwickshire they are found to be absent, and must therefore have thinned out against the ridge of ancient rocks which underlie the Charnwood and Nuneaton district. Neither are they found in the South Staffordshire coalfield.

Middle Coal-measures.—This group has a wider extension than those below. It is also a more varied series, consisting of grey shales and grey or white sandstones with many seams of coal and of ironstone (carbonate of iron), this association of coals and ironstones in the same series of beds making it commercially the most important group in the whole series.

It is believed to attain its greatest thickness in Lancashire, where if

measured from the Worsley 4-foot coal to the flags below the Arley mine coal, the thickness is about 3500 feet. In Yorkshire and Nottingham these measures are from 2000 to 3000 feet thick, and are so entirely like those of Lancashire that several of the Yorkshire coal-seams can be identified with their counterparts on the west; thus the "Silkstone" of Yorkshire is the "Arley mine" of Lancashire. Layers of nodular carbonate of iron are frequent and have been largely worked. Some of the Coal-measure sandstones near Pontefract, Ackworth, and Rotherham in Yorkshire are stained red and were formerly mistaken for beds of Permian age.

In Leicestershire these measures are about 1500 feet thick with ten good coal-seams, but in Warwickshire they have shrunk to about 700 feet with only five workable coals.

In North Staffordshire they are probably about 1600 feet if the group is restricted within approximately the same horizons, and in South Staffordshire they are about 1000 feet thick at the northern end of the coalfield, lessening to 500 feet at the southern end, but this may not be entirely due to thinning. They contain many good coal-seams, and it is a curious fact that some fourteen seams which are distinct in the north coalesce southward by the thinning out of the intervening measures till they form one bed of coal, from 25 to 30 feet thick, which is then known as the "Thick Coal." In Staffordshire three species of *Anthracomya* are common in these beds—*A. Wardi*, *A. pulchra*, and *Adamsi*.

Transition and Upper Coal-measures.—These stages have been most completely studied in North Staffordshire and Flint, where Dr. W. Gibson found reason to include certain red and purple sandstones which had previously been referred to the Permian. For these he proposed the name "Keele Series," but they should be known as the Keele Beds since they are only part of a "series." The following is an abstract of the succession established by Mr. Gibson:—²

		Feet.
Upper C.M. or Keele Beds.	Red and purple sandstones and marls with three thin layers of <i>Spirorbis</i> limestone. Fossils, a few plants and Entomostraca	700
	Newcastle Group. Grey sandstones and shales with four thin seams of coal and a limestone at the base. Fossils, many ferns and plants (<i>Sigillaria Brardi</i>).	300
Transition Coal- measures.	Etruria marls. Red and purple marls and clays with thin bands of green grit and a limestone near the base. The clays are largely used for pottery	800
	Blackband Group. Grey sandstones and marls with blackband ironstones and thin seams of coal. <i>Anthracomya Phillipsi</i> and fish teeth	300 to 450
	Total about	2200

There is a similar set of beds near Manchester, but they have not yet been fully correlated with the above.

On the eastern side of the Pennine range these beds are concealed beneath the newer rocks, but have recently been proved in a boring at Thurgarton, near Southwell, in Nottinghamshire. The cores indicate a succession like that of North Staffordshire, but with a less thickness. Mr. W. Gibson (*op. cit.* p. 262) gives it as follows:—

	Feet.
Permian (Marl slate).	
Keele Beds { Red sandstone and marl with <i>Neuropteris rarinervis</i> and <i>Pecopteris Miltoni</i>	188
Newcastle Beds { Grey sandstones and shales with a seam of coal	91
Etruria marls: red marls and green grits	257
Grey Coal-measures below.

Fig. 99.—SECTION ACROSS THE MADELEY DISTRICT, COALBROOKDALE (W. J. Clarke).

a. Middle Coal-measures.

b. Upper Coal-measures.

In Yorkshire near Rotherham there are some red marls and sandstones which are classed as Upper Coal-measures, and probably belong to the Etruria marls, but only 54 feet of them are seen.

When these Upper Coal-measures recur in the more southern coalfields of Shropshire, South Stafford, and Warwick, they are found to be more or less unconformable to those below. This is markedly the case in the Coalbrookdale district of Shropshire, where the whole Carboniferous succession is as follows:—

	Feet.
Upper and Trans. C.M. { Red and purple sandstones and marls (? Keele Beds)	800
{ Mottled clays and greenish grits with a limestone containing <i>Spirorbis</i> (Freshwater Beds)	440
Middle Coal-measures with a band containing marine fossils	600
Lower Coal-measures or Millstone grit, thinning out south	0 to 100
Avonian limestones and shales (<i>Productus giganteus</i>)	0 to 180
	Up to 2100

The lower beds, including the Middle Coal-measures, lie in a

broad syncline (see Fig. 99), while the Upper Measures are nearly horizontal; the base of the latter being a mottled clay known as "calaminker" overlain by a bed of gravel or conglomerate called the "Rough Rock." As this series is traced southwards the lower members thin out and disappear, while the Middle Measures overstep the Millstone grit so as to rest on the Old Red Sandstone, and this is their position in the Forest of Wyre west of Kidderminster and around Bewdley.

In South Staffordshire there appears to be a similar break between the Middle and Upper Measures, for the diminution in the thickness of the Middle Group toward the south is probably in part owing to an overstep on the part of the Upper Measures. According to Professor Lapworth the succession south of Dudley is as follows:—

			Feet.
Upper	{ Red sandstones and marls (Hunnington)	. .	1300
and	{ Grey sandstones and marls (Halesowen)	. .	800
Trans. C.M.	{ Red marls and greenish sandstones	. .	800
Middle or productive Coal-measures		. .	500
<hr/>			
			3400

The same succession is found in Warwickshire.

From the preceding account of the stratigraphical arrangement of the several members of the Westphalian Series in this region it will be seen that they all become thinner southwards, each stage passing beyond the limits of the one below farther and farther on to the Midland area which was land in Avonian time. Moreover, it is apparent that there was some terrestrial disturbance and uplift in this southern part of the region after the formation of the Middle Coal-measures.

It may also be inferred that the main mass of the Westphalian Series above described was deposited in a trough which extended from west to east across what is now the Pennine range, and that this trough was continually deepened by subsidence, while in the area to the south of it subsidence was interrupted by stationary epochs and at one time by an uplift with consequent flexure and erosion.

Further, the student should note that the existing coalfields on each side of the Pennine ridge still extend far below the newer beds which cover their outer parts. Thus the Lancashire coalfield probably passes westward below Liverpool Bay, and the Yorkshire coalfield is known to extend as far as Haxey in Lincolnshire, where a boring has been carried to a depth of 3185 feet passing through 1457 feet of Coal-measures. It is believed that the subterranean extension of this coalfield reaches as far eastward as Lincoln and Brigg.

2. Cumberland and Northumberland Area

In the north of England there are two coalfields which, though now far apart, were originally parts of one continuous sheet of Coal-measures which spread over the whole of the Lake District and across the broad Pennine Hills. These are the Newcastle coalfield, occupying parts of Durham and Northumberland, and the Whitehaven coalfield in Cumberland. Remnants of the connecting strata have been preserved in the small Canonbie coalfield on the border of Dumfries, in a faulted tract south of Haltwhistle in Northumberland, another at Argill near Brough in Westmoreland, and in patches of Millstone Grit on the west side of the Eden Valley.

The Newcastle coalfield is the largest of these tracts; it extends from the northern side of the Tees valley west of Darlington to the mouth of the river Coquet, a distance of about 60 miles. It is limited on the south by an anticlinal flexure which runs from Barnard Castle to the mouth of the Tees, and the Millstone grit runs into the sea near Alnmouth, so that the eastern part of the coalfield passes beneath the floor of the North Sea.

Millstone Grit.—This division is of small thickness, and it is doubtful what beds should be assigned to it. In Yorkshire the Millstone grits thin rapidly as they are followed northward, and in the North Riding are not more than 600 feet thick. Some of the grits, however, are believed to come in again between Teesdale and Tynedale, and have been mapped as forming broad plateaus on the high fells of West Durham, but in this area they lose their coarse gritty character and become indistinguishable from the sandstones and flagstones of the Gannister measures.

Lower Coal-measures.—These beds likewise become much thinner in a northerly direction, so that in Northumberland the whole thickness between the Felltop limestone and the Brockwell coal, which is the lowest workable seam, is only about 350 feet. Of this Mr. Lebour assigns 150 feet to the Gannister measures, and in this thickness there are two seams of coal. A few marine fossils such as *Aviculopecten papyraceus* and stems of crinoids have been found in these beds.

The Middle Coal-measures maintain their thickness, which in Durham is estimated at 2000 feet, and they contain some twenty good seams of coal, including the Brockwell seam at the base and the High Main seam, which is the highest known seam in the series. Besides these there are many minor or less valuable seams, bringing the total number to over sixty. Some of the shales contain nodules and bands of ironstone which have occasionally been

worked, and some of these are so full of *Carbonicola* shells that they are known as "mussel bands." The sandstones are used for building purposes, and one bed, known locally as the "grindstone post," furnishes the celebrated Newcastle grindstones. No true Upper Coal-measures come into this area, though they may exist under the North Sea.

The Cumberland or Whitehaven coalfield borders the western coast from Whitehaven to Maryport and then runs north-eastward in a narrow tract which is faulted down between the Permian Beds and the Carboniferous limestones. The whole area, indeed, is so broken by faults that the thickness of the Coal-measures is not known, but believed to be over 1500 feet. Lithologically the series is divisible into (1) Productive Measures and (2) the Whitehaven Sandstone; but from an examination of the plant remains Mr. Arber groups the beds in the following manner:—

		Feet.
Whitehaven	Upper division=Transition Beds	418
Sandstone	Lower division	200
Productive	Upper division	450
Measures	Lower division=Lower C.M.	800

Both divisions of the Whitehaven Sandstone consist of purple sandstones, shales, and conglomerates, which weather to reddish tints, and the upper division includes a bed of *Spirorbis* limestone.

The Canonbie basin though small is interesting because it is deep enough to bring in still higher beds, and because the strata resemble the English Series more than the Scotch Coal-measures. The following abstract is taken from the full account given by Messrs. Peach and Horne:—

		Feet.
Upper	{ Red and purple sandstones and shales with a <i>Spir-</i> <i>orbis</i> limestone and 2 seams of ironstone . . . }	1500
Middle—	White sandstones, grey shales and coals . . .	500
Lower—	Grey sandstones, shales and coals . . .	750
M. Grit	{ Massive sandstones, some coarse, with shales and thin coal-seams . . . }	550
		<hr/> 3400

3. Scotland

The Westphalian Series is not so fully developed in Scotland as it is in Central England, but it is curiously different from that of Northumberland, for the Lower Coal-measures are of considerable thickness, while the Middle Division, which is the most productive part of the English Series, has a very different facies in Scotland, its beds being often called the "barren" measures because they contain no coal-seams. There are four separate coalfields occurring

in three basin-shaped tracts, namely that of Midlothian and Fife on the east, of Lanark and Stirling in the centre, and of Ayrshire on the west.

Millstone Grit.—In the counties of Edinburgh, Fife, Stirling, and Lanark the upper limestones are succeeded by a set of pale red and yellow sandstones in thick beds with occasional layers of shale. This group of sandstones is generally known as the Roslin Sandstone from its fine exposure near that place. Its thickness near Edinburgh and north of the Forth is from 500 to 600 feet, but it thins from the north-east to south-west; in Lanark it is only from 90 to 100 feet, and farther west, in Ayrshire, it is so thin as not to be definitely separable from the Coal-measures.

Recent examination of the plant remains by Dr. Kidston has led to the recognition of a palæontological break in this set of beds,³ and the fact is confirmed by Dr. Traquair's study of the fish remains; so that the lower part of the Roslin sandstone is now grouped as "Lower Carboniferous" (*i.e.* Avonian), and the higher part as "Upper Carboniferous" (*i.e.* Westphalian). In the Edinburgh district the line of division is drawn near a marine band about 230 feet above the highest limestone. The lower beds include several bands containing marine fossils, and *Sphenopteris* is the only fern-plant; while in the upper part plant remains are more abundant, species of *Alethopteris*, *Neuropteris*, and *Mariopteris* being the most frequent with several species of *Sigillaria* which range upward but not downward. Mr. Arber informs me that as a matter of fact no true species is common to the two floras found in the Roslin Sandstone.

Lower Coal-measures.—These measures attain a considerable thickness, about 1200 feet in Fife and Midlothian, from 1200 to 1500 in Lanark, and about 1300 in the Clyde Basin. They consist of grey and white sandstones, with shales, coals, fireclays, and ironstones, and ten of the coal-seams are from 2 to 5 feet in thickness. In Lanark and the Clyde basin the base of the series is taken at the slaty-band ironstone, and there are several other continuous beds of blackband ironstone which are of much commercial importance.

These measures contain a flora which is pronounced by Dr. Kidston to be the same as that of the Lower Coal-measures of England. The commonest plants are *Neuropteris heterophylla*, *N. gigantea*, and *Sphenopteris latifolia*. They also include two marine bands, one near the base containing *Schizodus deltoideus*, *Conularia quadrisulcata*, *Lingula mytiloides*, and *Orbiculoidea nitida*; and another above the "Ell" coal containing the same *Conularia* and *Orbiculoidea* with *Productus scabriculus*, *Bellerophon Urei*, and *Aviculopecten papyraceus*.

Middle Coal-measures.—These were formerly referred to the Upper stage because they consist chiefly of red sandstones and shales, and because in some districts they appear to be unconformable to the Lower Measures. From a study of the plant remains, however, Dr. Kidston considers them to belong to the Middle Measures.

The group has a maximum thickness of 900 feet in Fife, where it comprises red sandstones, red and purple clays, with some thin seams of coal and ironstone.

In Ayrshire the unconformity at the base of these measures is very marked, for they steal across the outcrops of the Lower Coal-measures until they rest on the uppermost limestone of the Lower Carboniferous, the Millstone Grit being absent as above stated. In the Ayr coalfield these beds include a thin band of fine white limestone containing *Spirorbis carbonarius*. A few Coal-measure plants have also been obtained from them.

Around Sanquhar in Nithsdale, Dumfries, there is an outlying tract of Coal-measures which rest directly on the Ordovician rocks south of the boundary fault. It has recently been proved that these include both Lower and Middle Measures, and their occurrence shows that Nithsdale became a strait connecting the Ayrshire and Cumberland basins across a ridge which had previously been an island.

4. Ireland

Rocks of Upper Carboniferous age occur in several parts of Ireland, but the principal coalfields are four in number, two in the north and two in the south. Of these the following is a brief account.

Southern Counties.—One extensive area occupies parts of the counties of Clare, Limerick, Kerry, and Cork, but the coal-seams in this region are few and of variable thickness, so that commercially it is less important than the "Leinster coalfield," which occupies parts of Tipperary, Kilkenny, and Queen's County. The succession in both these areas is similar, but a greater thickness of the Middle Coal-measures comes into the western basin. The groups recognised are :—

	Munster.	Leinster.
4. <i>Middle Coal-measures</i> with several good seams of coal. Fossils are freshwater Mollusca, Crustacea, and Amphibia	2000	800
3. <i>Lower Coal-measures</i> with thin coals and shale roofs containing marine shells	900	600
2. <i>Flagstone group</i> , micaceous flagstones and shales	500	300
	<hr/> 3400	<hr/> 1700

The Flagstone Group is the equivalent of the Millstone Grit of Bristol and South Wales, and the true Lower Coal-measures are the beds which overlies these flagstones, many of the same marine shells occurring in them as in the Gannister Beds of Northern England.⁴ The Jarrow collieries in Queen's County are known for the number of Amphibian remains which have been obtained from them.

Northern Counties.—The most important tract in the north is the Tyrone coalfield, which lies to the north of Dungannon and contains many good seams of bituminous coal. The succession as given by Mr. Hardman⁵ is as follows:—

	Feet.
<i>Middle Coal-measures.</i> —Soft sandstones and shales with coals, fireclays, and ironstones	930
<i>Lower Coal-measures.</i> —Hard sandstones and shales with a few thin coals and ironstones	1000
<i>Millstone Grit.</i> —Coarse grits and sandstones	60 to 200
	About 2000

Upper Carboniferous rocks occupy a considerable area in the counties of Leitrim and Fermanagh, and their sequence is the same as in Tyrone, but only part of the Lower Coal-measures come in above the Millstone Grit.

5. South Wales and Bristol Area

This area exhibits a different development of the Westphalian Series from that found in other parts of the British Isles, and it is not yet certain how far the natural divisions of the series in this southern area can be compared and correlated with those of more northern districts. Moreover, the succession found in the great coalfield of South Wales is not the same as that occurring in Bristol and Somerset, and the differences between the two areas may be tabulated as follows:—

South Wales.	Bristol and Somerset.
Upper Coal Series (= Upper C.M.).	Radstock Beds } Upper C.M.
Pennant Grit Series (= Transition C.M.).	Farrington Beds } Trans. C.M.
Lower Coal Series (= Middle C.M.).	Pennant Grits } Vobster Group } (Not represented.)
"Millstone Grit Series" (of doubtful age).	"Millstone Grit" (partly of Avonian age)

In the Bristol coalfield the Avonian limestones pass up through shales into the Millstone Grit, the lower part of which probably represents the Yoredale Beds of northern areas (see p. 253). As to the age of the higher part there is no evidence, but there seems to

be a break at the top of the sandstones, for there is nothing comparable to the Lower or to the Middle Coal-measures of the Midlands, at any rate from a palæontological point of view.

In South Wales the so-called Millstone grit may be of any age, for there appears to be a break at the base of it, and the overlying beds which have hitherto been called "Lower Coal-measures" contain the flora of the middle stage, and must be classed as Middle Coal-measures. They everywhere rest on a sandstone which is known as the Farewell Rock, and though this is at present grouped with the Millstone grit it may properly belong to the overlying Coal-measure Group.

In the following account the stages found in South Wales will be described first, as the succession is there more complete.

Millstone Grits.—In South Wales the group is very variable. At the eastern end of the basin north of Cardiff it is about 460 feet thick, consisting of a pebbly grit at the base, of shales and sandstones in the middle, and a massive sandstone (the Farewell Rock) at the top. Westward, however, the group expands to a thickness of over 1500 feet, the greater part consisting of dark-grey shale, but always having the Farewell Rock above, while the basal grits are sometimes present and sometimes thin out, so that in Gower, where it is absent, no line can be drawn between the Bishopston cherts and shales and the overlying barren shales.⁶

The normal succession is well developed in the Ammanford district on the northern outcrop, where the thicknesses are :—

	Feet.
Farewell Rock—green and white sandstones . .	about 200
Dark barren shales with bands of sandstone . .	„ 500
Quartzitic grits with some bands of shale . .	„ 600

In the Bristol and Somerset Coalfield the fine-grained sandstones which have been called Millstone Grit form a complete ring round the Coal-measure basins, but are apparently an upward continuation of the Avonian Series, and the relation of their highest beds to the overlying shales has not yet been ascertained. In most places they are about 1000 feet thick, but in the Mendip district they have thinned to 500 feet.

Middle Stage.—According to the evidence of the plants this only occurs in South Wales where it varies much in thickness, and like other members of the system expands toward the west and south-west. Thus at the eastern end of the basin it is only from 625 to 850 feet thick, but in the centre it is about 1400 feet, and near the south-west margin upwards of 4000 feet. This expansion appears to be due not only to the increased thickness of sandstones and shales, but also to the incoming of fresh

Fig. 100.—DIAGRAMMATIC SECTION ACROSS THE BRISTOL COALFIELD (Professor E. Hull). Distance about 15 miles.

Fig. 101.—SECTION ACROSS THE COALFIELD OF SOUTH WALES (Professor E. Hull). Distance about 20 miles.

measures, and more coal-seams toward the south-west. Many of the coal-seams are not persistent, and it is not easy to correlate the seams which occur in different parts of the basin.

Transition Stage.—In South Wales this stage is represented by the Pennant Grit Series, which consists of massive felspathic sandstones or fine-grained grits, with some subordinate bands of shale and seams of coal, and it forms the greater part of the high central moorland plateau which is known as the Mynydd. Near Pontypool on the east it is only about 800 feet thick and the coal-seams are thin, but west of Taff Vale the group rapidly thickens and workable coal-seams set in, so that near Swansea it is over 3000 feet thick, and contains fifteen good seams of coal.

In the Bristol coalfield the Transition stage includes two distinct groups, the Vobster Coal-measures below and the Pennant Grit above. The Vobster Beds consist principally of shales with some sandstones and many seams of coal, and many of the shale bands contain ironstone nodules, so that these measures are rich in coal and iron. The thickness is about 2000 feet, and in the central part of the area (east of Bristol) there are twenty-six coal-seams, but many of these are thin and disappear both to the north and south.

The Bristol measures include several bands which contain marine shells, and from these Mr. H. Bolton has obtained no fewer than forty-three species. The commonest are *Nucula equalis*, *Posidoniella levis*, *Schizodus antiquus*, *Lingula mytiloides*, *Glyphioceras carbonarium*, and *Gastrioceras Listeri*. *Pterinopecten papyraceus* also occurs, and by comparison with the list on p. 293 it will be seen that the shells hardly support the evidence of the plants. Mr. Bolton compares the fauna with that of the Gin Mine band in North Staffordshire, which, according to Dr. Kidston, should be placed in the Lower Coal-measures.

The precise age of the Pennant Grits in the Bristol coalfield is not yet known; they may belong to the Transition or to the Upper Coal-measures. They form a sandstone group from 1000 to 1700 feet thick, the prevalent material being a hard grey felspathic sandstone, which makes a durable building stone, and lies in thick beds, so that it can be cut as a freestone. There are some bands of shale and four workable seams of coal.

Upper Coal-measures.—These form a variable series of grey shales, light-coloured sandstones, and coals, which appears to be an expanded equivalent of the red Upper Coal-measures of more northern coalfields.

In South Wales, near Swansea, the group is very thick, having been estimated at about 3000 feet (Pellengare Series).

All the coal-seams in South Wales undergo a change of character as they are followed from east to west, the seams which are bituminous house-coals in the east becoming hard steam-coals in the central parts of the basin and passing westward into stone-coal or anthracite. It is also found that the coals of the upper measures are more bituminous than those of the lower.

In the Bristol coalfield a thickness of about 2000 feet is found, although the summit is nowhere seen; it is divided into two parts, the lower portion or Farrington Group occurring in both the northern and southern basins, the upper portion or Radstock Group only coming into the southern or Somerset basin.

The small coalfield of the Forest of Dean calls for some notice, because previous correlations of the beds with those of the South Wales and Bristol basins have been altered by a recent study of the fossil plants. It was supposed that there was an upper set of Coal-measures underlain by an equivalent of the Pennant grits. It now appears, however, that all the productive Coal-measures belong to the upper stage, and that the supposed Pennant grits are merely a set of massive sandstones in the lower part of this stage, which thus consists of the following members:—

	Feet.
Upper shales and coals (10 seams)	1480
Thick sandstones with 3 coal-seams	850
Trenchard sandstones and 2 coals	77
	<hr/>
	2407

These beds are directly underlain by the so-called Millstone Grit, and consequently there is no representative of either the Middle or Lower Coal-measures.

6. *Devon and Cornwall*

The "Upper Carboniferous" or Westphalian Series of this area has hitherto generally been called the *Culm-measures*, but this term has become misleading and should be dropped, for they are simply barren Coal-measures and are not the equivalents of the strata known as Culm-measures in Central Europe.

According to Mr. Ussher⁷ the series is divisible into two parts or stages, which he called Middle and Upper Culm-measures, but this is not confirmed by Mr. Arber who regards the whole succession of beds as forming a single lithological division, the so-called "Eggesford Grits" being only a local variation of type which he has recognised in several localities.⁸

Mr. Arber describes the series as consisting essentially of fine-grained sandstones or grits and shales in alternating bands. The beds are highly flexured and broken by faults, many of the sharp

anticlinal folds seen in the coast-sections being faulted at the crest and sometimes overthrust. The sandstones are hard, of grey, lilac or brownish tints, and usually from 4 to 5 feet thick, but sometimes less; the shales and mudstones are grey or red. These strata include beds of hard impure coal, generally known as *culm*, and there are also thin unpersistent beds of limestone as well as layers of calcareous nodules.

The nodules near Bideford and Instow have yielded marine shells chiefly of *Gastrioceras carbonarium*, *G. Listeri*, *Dimorphoceras Gilbertsoni*, *Pterinopecten papyraceus*, and *Posidoniella levis*; and of this assemblage Dr. W. Hind remarks that it resembles that of the Bullion Mine seam in the Lower Coal-measures of Lancashire. In the same district plant remains have been collected by Mr. T. Rogers and Mr. N. Arber, and the latter has shown that the flora is that of the Middle, not of the Lower Coal-measures, so that here, as in the Bristol area, there is a conflict between the evidence of the fauna and the flora. Nothing to indicate the presence of Transition or true Upper Measures has yet been found in Devonshire.

In the southern part of the area near Chudleigh and Newton Abbot the base of the Westphalian Series is a conglomerate which lies unconformably on the chert-beds of the Lower Series and in some places appears to overstep them on to the Devonian rocks. It contains pebbles of chert and limestone and a few of granite, which, however, is not like that of Dartmoor. This bed is overlain by a set of alternating grits and shales like those of Bideford, and near Exeter Mr. T. G. Collins has recently obtained fossils which show that they occupy a low position in the series.

D. CONTINENTAL EQUIVALENTS

1. *Westphalia*

We take this area first because the succession of beds therein found is regarded on the continent as the typical development of the series. De Lapparent has well remarked the area might be appropriately called the basin of Münster, since that city overlies the central portion of it. It is only in the southern part of the basin that the Carboniferous rocks come to the surface, the greater part being concealed beneath the Jurassic and Cretaceous strata which form the Westphalian plain. The surface tract extends from near Dusseldorf on the Rhine, by Hagen and Arnsberg to Brilon and Marsburg, a distance of about 90 miles. From this outcrop the beds dip northwards and then extend in a series of undulations beneath the great plain, probably reaching as far as the

Teutoburger Wald before they finally rise again to terminate the broad syncline. The student should refer to Stanford's geological map of Central Europe.

At the base of the series is a thick mass of sandstones (Flotzeere Sandstein), some of which are coarse and pebbly. These beds occupy the place of our Millstone grit and are said to be without fossils. The whole series is believed to be over 11,000 feet thick, and has been divided into the following groups:—

	Feet.
6. Group with highly bituminous coals (35 seams) . . .	3000
5. " less bituminous coals (8 seams) . . .	1000
4. " good coking coals (19 seams) . . .	1200
3. " fairly good coals (7 seams) . . .	400
2. " poor coals (21 seams) . . .	2500
1. The Flotzeere sandstones . . .	3000

In this succession Cremer has recognised four plant assemblages.

Zone *d*=6, with *Neuropteris rarinervis* and *N. tenuifolia*.

Zone *c*=5, with *Sphenopteris obtusiloba* and *Lonchopteris*.

Zone *b*=3 and 4, with *Sphen. trifoliata* and *Alethopteris lonchitica*.

Zone *a*=2, with *Neuropteris Schlehani*.

It is specially to be noted that though the succession is complete, and every part of it seems to be fully developed, the flora of No. 2 (zone *a*) is not that of our Lower Coal-measures. It contains, however, several bands in which marine fossils occur, the lowest of these being about 600 feet above the base and yielding *Gastrioceras Listeri* with other species which in England do not range above the lower division.

2. Belgium and France

West of the Rhine, a long but rather narrow tract of Carboniferous rocks comes in on the north flank of the high ground formed by the Cambrian and Devonian rocks (see p. 216) and stretches continuously from Aix-la-Chapelle by Liège, Namur, and Mons, and thence still farther under the cover of Neozoic deposits by Valenciennes, Douai, and Bethune to the Boulonnais.

Throughout this tract of country the Carboniferous strata are sharply flexured and much broken by faults. Their southern boundary is generally an overthrust fault with a southerly hade and such a great displacement that the Devonian rocks have been carried over the Coal-measures which are in some places actually worked beneath this cover of older rocks.

In Belgium the representative of the Millstone grit seems to be very thin, but it forms a constant band of coarse grit from 30 to

40 feet thick, and thus separates the Viséan shales (see p. 279) from the overlying Coal-measures. These latter have been divided by Zeiller⁹ into the following zones :—

4. Zone of the "charbons flénus" (gas-coals) with *Pecopteris nervosa*, *P. dentata*, *Neuropteris rarinervis*, *Sphenopteris obtusiloba*, and *Sigillaria tessellata*.
3. Zone of "charbons gras," with *Sphenopteris nummularia*, *Neuropteris gigantea*, *Alethopteris Serli*, and *Sigillaria polyplexa*.
2. Zone of "charbons demigras—" *Sphenopteris trifoliata*, *Lonchopteris Bricei*, *Aleth. Darreuxi*, and *Sigillaria scutellata*.
1. Zone of "charbons maigres—" *Neuropteris Schlehani*, *Alethopteris lochitica*, *Sigillaria elegans*, and some *Lepidodendra*.

It will be noticed that the succession of coals and of plant-zones is similar to that of Westphalia. The total thickness of this series near Boussu west of Mons is about 2400 metres (= 8000 feet), and near Douai it is estimated to be more than 2500 metres.

In the Boulonnais, near Leulingham, Locquinghem, and Ferques, Coal-measures are being worked under overthrust masses of Carboniferous limestone; and another trough appears to come in to the north of these overthrusts, part of it lying below Dover where Coal-measures were reached by boring at a depth of 1100 feet from the surface. The same series of troughs and faulted blocks is probably continued westward under the south of England till it emerges again in the coalfields of Bristol and Somerset.

3. Sarrebruck Area

Just as the Belgian coalfields lie in a synclinal trough on the northern flank of the broad tract of Devonian rocks which stretches across the Ardennes and the Rhine Valley, so also we find another syncline on its southern flank. The exposed portion of this syncline is known as the Sarrebruck basin, but it is very likely to have a prolongation westward beneath Metz, though probably at too great a depth to be attainable (see Fig. 103).

The deposits in this southern basin, however, differ much from those in the northern, for not only is there an entire absence of the Dinantian Series, but the greater part of the Westphalian is also wanting, and the lowest beds in the basin must rest unconformably upon the Lower Devonian or still older rocks. The bottom of the basin in its deepest part has not yet been reached, but the lowest beds traversed correspond with the highest part of the Belgian Series (the charbons flénus) and are covered by beds which resemble our Upper Coal-measures, while these latter are succeeded by the still higher Stephanian Series. The Westphalian part of the succession is as follows :—

	Feet.
3. Purple sandstone and shales with thin coals . . . about	2000
2. Red sandstones and conglomerate at base	3500
1. Sandstones and shales, both red and grey, with 80 seams of bituminous coal	1500

4. Silesia, Moravia, and Poland

No large area of Westphalian strata is found again in Central Europe till we reach Silesia, where there are two basins or troughs, the one known as the Lower Silesian or Waldenburg trough and the other as the Upper Silesian basin. The first runs from the Eulengebirge and Waldenburg westward to Schatzlar in Bohemia, and is partly covered by Triassic and Cretaceous rocks. The second lies farther south, its north-east end resting on Devonian near Zuckmantel in Austrian Silesia, and extending south-west far into Moravia (to near Brünn). The thickness of beds in both these areas is considerable, and those of the Waldenburg trough were divided into two stages by Stur:—

2. Schatzlar Beds corresponding with those of Sarrebruck.
1. Waldenburg Beds, with a flora of Culm affinities.

He was inclined to class the lower beds with the underlying Culm, but Weiss regarded them as Westphalian, and Tietze has more recently shown that their equivalents in Moravia (the Ostrau Beds) contain a larger number of species belonging to the Schatzlar flora than to that of the Culm. The Ostrau Beds include several marine bands containing *Gastrioceras Listeri*, *Bellerophon Urei*, and other species which suggest a correlation with our Lower Coal-measures.

Still farther east a similar succession of Westphalian Beds occurs near Cracow in Poland, where it includes a marine band with *Spirifer mosquensis*, a species which does not exist in Western Europe, and marks a temporary incursion of the eastern or Moscovian Sea.

5. Russia

When we reach Central Russia we find the representatives of the Westphalian Series to be entirely of marine origin, estuarine and semi-terrestrial conditions only prevailing in the southern basin of Donetz.

In the Moscow basin the whole series consists of limestones, white or yellow in colour, some beds oolitic and some chalky, and many of them highly fossiliferous. This series is known as the *Moscovian*, and is about 1500 feet thick; it is specially characterised by *Spirifer mosquensis* and *Streptorhynchus (Meekella) eximius*, with the large Foraminifer called *Fusulina cylindrica*, which is sometimes so abundant as to form a *Fusulina* limestone.

These limestones are covered by other beds which also probably belong to the Westphalian Series, for they contain some species common in our Avonian Series, such as *Spirifer striatus*, *Productus cora*, and *P. semireticulatus*, together with species of *Syringopora*, *Lonsdaleia*, and other corals.

The Moscow basin, though it occupies an area of 13,000 square miles, is probably only a part of a great tract of Carboniferous rocks which underlies the broad Russian plain, for the beds pass in every direction underneath newer strata of Permian, Jurassic, and Cretaceous ages. Moreover they crop out again along the western flanks of the Ural Mountains in an almost continuous strip, and this (partly covered by Permian) is believed to extend northward to the shore of the Arctic Ocean.

In the Ural Mountains the Moscovian Series consists of limestones with bands of calcareous shale. *Spirifer mosquensis* and *Productus cora* are still characteristic fossils, but Cephalopoda are more frequent and include *Glyphioceras striolatum*, *Pronorites cyclobus*, and *Gastrioceras marianum*.

6. Mediterranean Region

A few tracts of Westphalian or Moscovian strata occur in Southern Europe, and they all resemble the Russian type more than that of the north-west. Thus in Austria sandstones and shales, with bands of *Fusulina* limestone, are infolded with Trias on the western borders of Styria; and again in Carinthia the Gailthal slates (Dinantian) are overlain by sandstones and shales succeeded by *Fusulina* limestones. A similar series is found to the south in Carniola, Croatia, Bosnia, and Herzegovina.

Westphalian Beds are said to occur in Corsica, and in Spain (Andalusia) there are Coal-measures with *Dictyopteris Brongniarti* and interbedded limestones with *Spirifer lineatus* and *Sp. mosquensis*. Again in Asturia the Sama slates with *Dictyopteris* and intercalations of marine beds with *Schizodus* and *Posidonomya* probably belong to the same series.

III. THE STEPHANIAN SERIES

As stated at the beginning of last chapter (p. 244), no representatives of the highest portion of the Carboniferous System occur in Britain. This gap in the geological record appears to be due to a general uplift of the whole of North-Western Europe, whereby the low-lying areas in which the older (Westphalian) Coal-measures had been accumulated were raised into dry land. This upheaval, moreover, was accompanied by volcanic disturbances and by crustal

compression, which resulted in the production of several systems of flexures, but especially of a great series of folds having a general direction from west to east.

This series of flexures is known as the Armorican or Hercynian System, and it extends from the south-west corner of Ireland through South Wales, Devon, and Cornwall. Thence it passes under the whole of Southern England and through the north-east of France and Belgium. Another part of the same series passes through Brittany and Normandy and under the Paris basin till it emerges in the Ardennes. The combined series then extends through the Rhine Province of Germany, through Westphalia and the rest of Germany to Poland and the northern border of Bohemia. These Armorican flexures are narrow and the synclines are deep; the folds are sometimes overthrust and often broken by faults.

North of this series of flexures in England we find another set, or rather two sets which cross one another nearly at right angles, and it is to the intersection of these two sets of folds that the production of Coal-measure basins is due. The one set runs approximately north and south, and is exemplified in the ridge of the Malvern and Abberley Hills, where Upper Coal-measures are included in one of the flexures, and yet the folding is shown to be pre-Permian by the position of Permian strata on a plane of erosion cut across these flexures. Farther north is the parallel anticline of the South Pennine area, which separates the flanking synclines occupied by the Coal-measures of Nottingham and Yorkshire on the one side and of North Stafford and Lancashire on the other side. Here again the pre-Permian age of the main flexures is indicated by the position of the Permian Beds overlying them in Nottinghamshire, though there may have been further uplifts in Triassic time, and still later in Tertiary times. The North Pennine faults in West Yorkshire, Westmoreland, and Cumberland were also in part pre-Permian.

The other set of flexures runs approximately from W.S.W. to E.N.E., and may be termed the Lancastrian Series. They differ markedly from the nearly parallel Armorican folds in being very broad and comparatively shallow undulations. Such is the broad anticline of the Ribble Valley and its continuation across Yorkshire, which passes eastward under the Permian of that county.

For a fuller account of these flexures the reader is referred to the new edition of my *Building of the British Isles* (1911), but which of the two series is the older has not yet been determined.

While uplift, disturbance, and erosion were going on in the north of Europe, deposition was still in progress farther south, and more especially over the eastern part of Europe. In the western

region deposition seems to have been restricted to certain shallow-water areas of a lacustrine character, and only portions of these remain in small isolated basins. It was only in the east over Russia and the Balkan provinces that open sea prevailed. Consequently there are two very different facies of this series, a western Coal-measure Group (with plants and freshwater fossils) to which the name *Stephanian* has been given from St. Etienne in France, and an eastern marine facies known as the *Uralian* from its development in the Ural Mountains. We can only give a brief account of these two facies.

A. THE STEPHANIAN FACIES

1. **The Flora.**—This is characterised by the abundance of certain species of *Pecopteris* (*P. arborescens*, *P. cyathea*, etc.), of *Callipteridium*, *Odontopteris*, of *Cordaites* and *Calamodendron* with the foliage known as *Annularia*, the non-ribbed *Sigillarias*, and finally by the appearance of *Teniopteris*, of the Conifer *Walchia* and the Cycads *Pterophyllum* and *Plagiozamites*. Three phases or stages have been recognised by M. Grandeury as existing where the Stephanian Series is complete; these are:—

3. Phase of *Calamodendrons*.

2. Phase of *Annularia stellata* and *Pecopteris cyathea*.

1. Phase of *Ann. sphenophylloides* and *P. neuropteroides*.

The Fauna is not a large one, consisting of some small freshwater Crustacea (*Estheria*, *Leaia*), a few Molluscs (*Anthracosia*), a number of insects, especially beetles (*Eoblattina*), and Phasmidæ (*Protophasma*, *Dictyoneura*); also some Fish and Amphibians.

2. **Stratigraphy.**—In France the Stephanian deposits occupy a number of small isolated basins or troughs, most of which are situate on the borders of the "Massif Central," though some occur in the middle of it (see map, Fig. 102). Many of these patches are doubtless portions of much larger areas or basins of deposition and were originally continuous, but no attempt has yet been made to ascertain which may have been connected with one another, and indeed most French geologists seem to assume that they were all disconnected.

The typical district of this region is that of St. Etienne in the Department of the Loire (see Fig. 104), where the succession is stated to be as follows:—

	Feet.
Coal-measures { 5. Bois d'Aveize Group	600
{ 4. Berard Group	1100
{ 3. St. Chamond Group	1800
2. Sterile Beds, conglomerates and sandstones	1500
1. Breccia resting on the Archæan rocks	600

sandstones and shales with some beds of coal (from 160 to 300 feet thick) overlain by a mass of sandstones and conglomerates more than 2000 feet thick.

Another small basin in the north, that of Commentry (Allier), is interesting in three respects. One is that it contains a very thick bed of coal (40 to 60 feet thick) which in certain directions splits up into 5 or 6 beds, separated by shales and sandstones, just as in the case of the "thick coal" of Staffordshire. Another point is that a shale 15 feet above this coal has yielded a large number of insect remains. Thirdly, one of the beds of sandstone passes at one place into a mass of breccia formed of angular blocks of gneiss and granulite which seem to represent a contemporaneous landslip from neighbouring high ground.

A few small tracts of Stephanian measures occur in Brittany and Normandy, and are mainly of importance because they occur within the region of Armorican flexures and show that deposition had not completely ceased in that region. The most northern of these is at Littry, south-west of Bayeux, the Coal-measures here resting directly on Brioverian slates and being conformably overlain by Permian Beds, and they belong, therefore, to the latest phase of the Stephanian.

In Germany the most western tract of Stephanian Coal-measures in the Germanic region is that of the Palatinate near Sarrebruck (see Fig. 103), where they are known as the Ottweiler Beds. Here they succeed the Westphalian Beds without any break, though they overlap the latter on to the Devonian; and they are also conformably overlain by Permian Beds. The greater part of the series consists of felspathic sandstone and conglomerate, testifying to the upheaval and rapid detrition of the country to the north of the basin; but both at the base and again at the top are a few hundred feet of finer sediments, chiefly grey shales with seams of coal. The total thickness is from 2000 to 3000 feet.

The small coalfields of Pilsen and Kradno in Bohemia are specially interesting because they exhibit a still more complete transition from Carboniferous to Permian and include a bed from which remains of many insects, fish, and Amphibia have been obtained by Dr. Fritsch. The plants in and above this bed are Carboniferous, while the vertebrate animals are closely related to forms which have been found in beds of Permian age: fish of the genera *Amblypterus*, *Acanthodes*, *Palæoniscus*, and *Xenacanthus*; Amphibians of the genera *Dendrerpedon*, *Sphenosaurus*, *Chelidosaurus*, *Limmerpedon*, *Keraderpedon*, *Urocordylus*, and *Hyalonotus*, some of which are figured in the *Geological Magazine* for 1885.

Fig. 103.—SECTION THROUGH THE SARREBRUCK DISTRICT (after R. Nasse).

Fig. 104.—SECTION ACROSS THE COALFIELD OF ST. ETIENNE (Loire).

Scale 4000 feet to an inch horizontal and vertical.

The following is a tabular view of the strata in the Pilsen basin, modified from that given by Feistmantel :—¹⁰

Permian	{ Red felspathic sandstones with <i>Araucarites</i> .
	{ Shales with ironstone nodules (Permian plants).
Stephanian	{ Shales with Carboniferous plants, a coal-seam and the Nurschau "gas-coal" (oil-shale).
	{ Lower shales with a coal-seam.

The plants in the Stephanian shales include *Calamites* (three species), *Sphenopteris Schlotheimi* and eight other species, *Odontopteris obtusiloba*, *Dictyopteris Brongniarti*, *Sigillaria distans*, and fragments of *Walchia*. Both Feistmantel and Römer correlate these beds with those of the Ottweiler Group. Further particulars will be found in the paper referred to.

B. URALIAN FACIES

1. **The Fauna.**—This is entirely marine in the more typical areas. Foraminifera play an important part in the formation of Uralian limestones, the principal genera being *Fusulina*, *Swagerina*, and *Doliolina*. A spiral Bryozoan, *Archimedes*, is also a common and characteristic fossil. Brachiopoda are abundant, especially the Terebratuloid *Dielasma*, the Rhynchonellid *Camarophoria*, and the Orthotetid *Meckella*. *Spirifers* are still common, and the persistent species *Productus cora* is abundant; *Chonetes* is represented by *C. uralicus*, and shells of the genus *Spiriferina* make their appearance, together with some which are closely allied to *Waldheimia*.

Of Mollusca the Lamellibranchs *Conocardium*, *Aviculopecten*, *Schizodus*, and other Carboniferous genera occur. The Gastropod *Omphalotrochus* is common, but Cephalopoda are not numerous; *Gastrioceras marianum* occurs throughout, and in the highest beds *Agathiceras uralicum* appears. A few trilobites also survive.

2. **Stratigraphy.**—The typical development of this series is found on the south-west side of the Urals in the basin of the river Ai (Province of Ufa), where the whole consists of limestone, and three stages or zones are recognised by Tschernyschew, viz. :—

3. Zone of *Swagerina princeps* and *Spirifer sarana*.
2. Zone of *Productus cora* and *Meckella eximia*.
1. Zone of *Omphalotrochus Whitneyi*.

The same succession is found in the Moscow basin and in the Tinian district in the north of Russia. The limestones of the middle zone are generally dolomitic.

On the eastern slopes of the Ural Mountains there is a much greater variety of sediments indicating the near proximity of land,

limestones being interbedded with marls and sandstones, clays and layers of gypsum; and the highest beds contain a Stephanian flora (*Pecopteris arborescens*, *Annularia longifolia*).

The Uralian Sea must have occupied the greater part of Russia, passing southward over the Crimea and south-eastward through the Balkans, Bosnia, Herzegovina, Carniola, and the Julian Alps. Farther west, in the Carnic Alps between Italy and the Tyrol, there is an interesting intercalation of the Uralian and Stephanian facies, *i.e.* of freshwater and marine beds. The following series has been described by Schellwein at Krone:—¹¹

Shales with *Spirophyton*.

Dark-grey limestones with *Fusulina* and *Swagerina*.

Sandstone with *Pecopteris* and *Annularia stellata*.

Bed containing marine shells.

Shales with *Annularia stellata* and other plants.

Shales and calcareous sandstones with *Camarophoria*, *Productus*, and *Phillipsia*.

Shales with *Pecopteris oreopteroides*.

Conglomerates at base (about 200 feet thick).

The total thickness of these beds is about 900 feet, and they are overlain by another *Fusulina* limestone which is of a *light-grey* colour and contains a Lower Permian fauna. How much farther west the Uralian Sea extended is not yet known, for no marine strata of this age have been found in Italy or Spain, though deposits with a Stephanian flora occur in both countries.

C. THE FORMATION OF COAL-SEAMS

The most important point connected with the deposition and distribution of the Coal-measures is the formation of coals; what they are made of, and how they were accumulated. The reader will find this subject well treated in a little book, *On the Natural History of Coal* (Camb. Univ. Press), by Mr. N. Arber, but a brief summary of the current theories and modern views respecting the origin of coal may here be given.

A complete explanation of coal-seams must account for (1) the source of the carbonaceous material; (2) the different existing varieties of coal; (3) the frequent alternations of coals, clays, shales, and sandstones; (4) the great extent of some single beds of coal. The reader is probably aware that there are many kinds of coal which go by different names according to their chemical composition and physical peculiarities. There is so-called "Brown-coal," which is little more than lignite or fossil wood; there is glossy Cannel coal, which does not soil the fingers and burns with a clear, continuous flame; there are the Humic or so-called

Bituminous coals, which vary in their gas-producing qualities ; and lastly, there are the hard coals—Steam-coal and Anthracite—the last differing in being smokeless when burnt.

It is now generally agreed that the original substance of all kinds of coal was vegetable matter of some kind, and that many kinds owe their peculiarities to differences in the nature of the vegetable matter of which they were originally composed. Thus the Toul coal of Russia consists entirely of sheets of the bark of the tree called *Bothrodendron*, and this is so little altered that, when exposed to the weather, it splits up into thin layers. Other coals appear to have been composed of a mixture of woody tissue with leaves and fronds of fern-like plants. Some beds consist of the spores or sporangia of Carboniferous plants ; thus Cannel coal is mainly composed of Lycopod-spores, and some Boghead coals of closely packed cellular bodies which are either spores or gelatinous algæ arising from their decay.

Some other varieties of coal, however, are due to the amount of chemical change which the substance has undergone since its original deposition and burial in the earth's crust, as well as to the varying degrees of pressure to which the strata have been subjected at different places. These influences appear to have led to a concentration of carbon in the older coals, or rather to an increase in the proportion of carbon to hydrogen.

Let us next consider the conditions under which the coal-seams are likely to have been accumulated, and it is evident that on this question we can learn much from a study of the associated sediments, that is to say from the general characters and contents of the whole series of measures of which the coal-seams form a part. These beds include sandstones which are generally of fine grain, and often show current bedding ; shales which are consolidated silts, *i.e.* sandy or micaceous muds deposited in successive layers or laminæ ; and clays which are more homogeneous muds. All these beds usually contain only remains of plants, and sometimes of insects, with bivalve shells such as *Anthracosia* and *Carbonicola*, which were of fresh or brackish-water habitat. Occasionally, however, there are bands which contain marine shells, and from these we may safely infer that the measures in which such beds occur were formed in swamps or marshes liable to incursions of the sea.

There is, in fact, no escape from the conclusion that the Lower and Middle Coal-measures of the British region, and probably most of those in the Continent, were formed in extensive swamps on the borders of sinking land, where the area of alluvial levels, swamps, and brackish lagoons was being continually enlarged at the expense of the sea by the process of silting up and by the outgrowth of

plants which, like modern mangroves, did not mind having their roots covered by salt water.

So far as to general conditions, but we have still to deal with the formation of the individual coal-seams, and to consider the way in which the coal-material may have been accumulated so as to form a seam or bed, for these are sometimes of great thickness, as much as 20 or 30 feet. There are a certain number of facts which seem to indicate that the vegetation from the decay of which a bed of coal was formed grew on the spot, while other facts have suggested the theory of drift-origin, *i.e.* that the vegetable materials were drifted by a current into their present situation.

Some writers have maintained the one, and some the other theory; but as Mr. Arber remarks, it is very likely that both theories are equally true, some coals having been formed in the one way and some in the other. He also points out that the significance of certain facts, often appealed to as evidence for one or the other theory, has been greatly exaggerated and misunderstood.

Thus the presence of an underclay containing many Stigmarian rootlets is no proof that the coal above has been formed *in situ* from plants which grew in that clay; neither does the fact that the roof-bed of a coal contains drifted plant remains prove the coal to have been formed by an accumulation of such drift. The formation of each bed of coal must be individually considered, and its own structure must especially be ascertained and noted; coals which consist entirely of one kind of material, such as the Cannels, were doubtless formed *in situ* from local growths, while some of those which consist of many sorts of plants may have been formed of drifted materials. Some seams may have been semi-terrestrial growths like modern peats, others were formed on the floors of large swamp lakes or in brackish-water lagoons, and in some cases these water spaces were clearly near to the estuary of a large river.

Finally, a few remarks may be made on the succession of plant-assemblages in the Coal-measures. That there is such a succession in the northern part of England admits of no doubt, and this same succession prevails over a large area, but whether it prevailed all over Europe, wherever the sequence was complete, has not yet been proved. Thus we have seen that what is known at present as the flora of the Lower Coal-measures cannot be recognised in South Wales, nor in the Bristol and Somerset coalfields, and further that it has not been found on the Continent except in a narrow zone of so-called Millstone grit. From the absence of this particular assemblage of plants, or rather from the absence of certain species, it has been inferred that the Lower Coal-measures are not represented in the more Southern areas.

It is doubtless true that from a botanical point of view the Millstone grit of the Pennine area is only the basal portion of the Lower Coal-measures, and that in other areas, such as Bristol and South Wales, the latter might be represented only by sandstones. Further, it is almost certain that the Millstone grit episode marks a general uplift of the whole British region, and a shallowing of all the areas in which deposition was taking place. This uplift may have been greater in some parts of the region than in others, and deposition may possibly have been stopped for a time in Southern England; but when we pass over into Belgium, and are asked to believe that divisions which have a thickness of 3000 to 4000 feet in England are entirely absent in that country, the case is different. There is no stratigraphical evidence of such a break, and if the absence of beds was due to uplift into dry land, signs of such a break should be clear and conspicuous.

Another and very different explanation presents itself which should be carefully considered by the botanists; this is that the absence of the species in question may be due to geographical limitation. It may be that the particular assemblage found in the lower stage of the northern region did not extend into the southern region, and that the southern assemblage did not extend into the northern region until the epoch of our Middle Coal-measures. In other words, the deposition of Coal-measures may have been contemporaneous in both regions throughout Westphalian times, but the succession of plant-assemblages was different in the two regions, and dependent on slight climatal differences north and south of a certain line of latitude. The truth of this theory must be tested by more careful zonal study both of the plants and of the shells.

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CHAPTER XI

THE PERMIAN SYSTEM

A. NOMENCLATURE AND SUBDIVISIONS

IN the early days of geological research all the strata which intervened between the Carboniferous and the Lias were classed together as the *New Red Sandstone*, but in 1841 and subsequent years Sir R. Murchison saw good reason to divide them into two great series and to believe that the lower series, on account of the Palæozoic aspect of its fauna, formed the summit of the Palæozoic succession, while the higher strata might be regarded as marking the beginning of Neozoic time.

Further, he found that this lower set of post-Carboniferous rocks was more fully developed in Russia than in any other part of Europe, and was especially well exposed in the province or ancient kingdom of Perm, whence he proposed to call them *Permian*.

Although the name Permian has been adopted in England, France, and Russia, it made its way very slowly in Germany, mainly because Murchison made mistakes in his grouping of the German rocks. In that country the strata which are really of Permian age fall into two strongly contrasted divisions, and just as the overlying *Trias* was named from its consisting of three such groups, so the term *Dyas* was proposed by Marcou in 1859 from the duality of the underlying system. This name was adopted by Geinitz, and was for a time much used on the continent, but Professor Kayser and others have more recently preferred the older name as on the whole a better one.

We have seen that where the Carboniferous System is complete and the Stephanian Series is fully developed there is a passage from it into the Permian. Further, where the Permian System is fully represented it consists of three stages or series, viz. (1) a series of beds like the underlying Coal-measures and containing a flora which does not differ much from the Stephanian; this has been

termed *Autunian* by the French geologists; (2) a mass of red sandstones well developed in Germany, where they are known as Rothliegende, but for which the name *Saxonian* has been proposed; (3) a group of limestones and marls, known in Germany as the Zechstein, but for which Renevier has proposed the name *Thuringian*.

In the British Isles there are several different facies of Permian, and there is little doubt that these include representatives of the Saxonian and Thuringian, but it is uncertain whether we have any equivalent of the Autunian. In Russia and Southern Asia the whole system consists of marine deposits with a much more varied fauna, and Russian geologists have proposed special names for parts of their succession. The correlation of English, German, and Russian divisions is shown below:—

English.	Germany.	Russia.
Magnesian limestone.	Thuringian.	Thuringian.
Penrith sandstone ?	Saxonian.	Kostromian.
Shropshire Permian ?	Autunian.	Artinskian.

B. LIFE OF THE PERIOD

1. *The Flora*

The Permian flora is on the whole very like that of the Carboniferous, fern-like Pteridophytes (*Pecopteris*, *Odontopteris*), Calamites, and Tree Ferns (*Psaronius*) being still the prevalent forms, and many of the same genera being present. At the same time it differs both in the absence of certain genera, in the greater relative development of others, especially *Callipteris*, and in the presence of numerous Mesozoic types, especially Coniferæ, Cycads, and Ginkgos. Thus *Sigillaria* and *Lepidodendron* have almost disappeared, while *Walchia* is abundant together with the new Coniferous genera *Ullmannia*. Among (?) Pteridosperms *Callipteris*, *Schizopteris*, and (in India and the southern hemisphere) *Glossopteris* are new and characteristic forms. *Cordaites* and *Cordioxylon* (= *Araucarites*) are not uncommon. Cycads are represented by *Pterophyllum* and *Plagiozamites*. Leaves of the curious tree called *Ginkgo*, still existing in China, are also found, as well as those of *Baiera*, a long extinct genus of similar affinities.

The following are some of the most characteristic species of plants:—

<i>Pteridospermæ.</i>	<i>Callipteris conferta</i> , <i>Neuropteris auriculata</i> , <i>Schizopteris Gunbeli</i> , <i>Teniopteris multinervis</i> .
<i>Equisetales.</i>	<i>Calamites gigas</i> , <i>Annularia stellata</i> .
<i>Coniferales.</i>	<i>Walchia piniformis</i> , <i>W. hypnoides</i> , <i>W. filiciformis</i> , <i>Ullmannia Bronni</i> , <i>U. Geinitzi</i> .

2. *The Fauna*

The Permian fauna is interesting because, as in that of the Carboniferous, it may be said that we possess remains not only of the marine fauna of the period, but also of the inhabitants of its great salt lakes as well as of the fresh waters and of the land.

The typical marine fauna is only found in the east of Europe,

Fig. 105.—GROUP OF PERMIAN FOSSILS.

<i>a.</i> <i>Walchia hypnoides</i> .	<i>c.</i> <i>Monotis speluncaria</i> .
<i>b.</i> <i>Schizodus Schlotheimi</i> .	<i>f.</i> <i>Strophalosia lamellosa</i> .
<i>c.</i> <i>Productus horridus</i> .	<i>g.</i> <i>Camarophoria Schlotheimi</i> .
<i>d.</i> <i>Spirifer alatus</i> .	<i>h.</i> <i>Fenestella retiformis</i> .

extending thence into Asia and America, but in later Permian time arms of this sea extended into Central Europe and into the British Isles, forming landlocked inland seas and large salt lakes resembling the Black Sea and the Caspian of the present day. In these areas we find a limited and dwarfed assemblage of marine species. This marine fauna is largely composed of species which belong to Carboniferous genera, but with these are associated some new forms. The following is a list of the prevalent genera, those to which an asterisk is appended being new introductions:—

<i>Bryozoa.</i>	<i>Fenestella</i> , <i>Synocladia</i> ,* <i>Acanthocladia</i> .
<i>Brachiopoda.</i>	<i>Diclasma</i> , <i>Camarophoria</i> , <i>Spirifer</i> , <i>Productus</i> , <i>Strophalosia</i> , <i>Aulosteges</i> .*
<i>Lamellibranchia.</i>	<i>Allorisma</i> , <i>Bakevellia</i> ,* <i>Gervillia</i> ,* (<i>Hoernesia</i>), <i>Schizodus</i> , <i>Pseudomonotis</i> , <i>Pleurophorus</i> .
<i>Gastropoda.</i>	<i>Bellerophon</i> , <i>Loxoneima</i> , <i>Naticopsis</i> , <i>Pleurotomaria</i> .
<i>Cephalopoda.</i>	<i>Medlicottia</i> ,* <i>Popanoceras</i> ,* <i>Thalassoceras</i> ,* <i>Cyclobus</i> , <i>Temnocheilus</i> .
<i>Pisces.</i>	<i>Acrolepis</i> ,* <i>Acanthodes</i> , <i>Cœlacanthus</i> , <i>Amblypterus</i> , <i>Palæoniscus</i> , <i>Xenacanthus</i> .*

Fig. 106.—SOME PERMIAN FISH.

- a. *Platsomus striatus*. b. *Cœlacanthus granulatus*.
c. *Palæoniscus comptus*.

The freshwater and terrestrial fauna is of special importance because it includes the earliest representatives of the Reptilia. The most conspicuous members of this fauna are:—

<i>Crustacea.</i>	<i>Uronectes</i> (= <i>Gampsonyx</i>).
<i>Amphibia.</i>	<i>Archegosaurus</i> , <i>Actinodon</i> , <i>Branchiosaurus</i> , <i>Dasyceps</i> , <i>Lepidotosaurus</i> .
<i>Reptilia.</i>	Two orders of Reptilia are represented, viz.:—(1) <i>Rhynchocephala</i> , by <i>Proterosaurus</i> and <i>Palæohatteria</i> ; (2) <i>Theromorpha</i> , by <i>Pareiasaurus</i> , <i>Elginia</i> , <i>Gordonia</i> , <i>Geikia</i> .

The following are some of the most characteristic species of the English and German Permian :—

<i>Bryozoa.</i>	<i>Fenestella retiformis</i> , <i>Synocladia virgulacea</i> .
<i>Brachiopoda.</i>	<i>Camarophoria Schlotheimi</i> , <i>Strophalosia lamellosa</i> , <i>St. Goldfussi</i> , <i>Productus horridus</i> , <i>Dielasma elongata</i> , <i>Spirifer alatus</i> , <i>Lingula Credneri</i> .
<i>Lamellibranchia.</i>	<i>Pseudomonotis speluncaria</i> , <i>Pleurophorus costatus</i> , <i>Gervilia (Bakewellia) antiqua</i> , <i>B. ceratophaga</i> , <i>Schizodus obscurus</i> , <i>S. Schlotheimi</i> .
<i>Gastropoda.</i>	<i>Loxonema fasciatum</i> , <i>Natica minima</i> , <i>Pleurotomaria</i> <i>antrina</i> , <i>Turbo mancuniensis</i> .
<i>Cephalopoda.</i>	<i>Temnocheilus Frieslebeni</i> .
<i>Pisces.</i>	<i>Platysomus striatus</i> , <i>P. gibbosus</i> , <i>Palæoniscus comptus</i> , <i>P. macropomus</i> , <i>Cœlacanthus granulatus</i> , <i>Acrolepis</i> <i>Sedgwickii</i> , <i>Rhabdolepis macropterus</i> .

C. BRITISH PERMIAN ROCKS

In spite of the fact that the British Permian succession is nowhere complete, and that it is uncertain whether the oldest part of the system is represented, Permian rocks cover considerable areas in England, and it will be convenient to describe them before dealing with those of the continent. The oldest Permian Beds must be those which are most nearly conformable to the Upper Carboniferous, and there can be no doubt that those of the Midland counties occupy this position. Those found in Devonshire resemble the Rothliegende of Germany, and may be of the same age; while there can be no doubt of the Thuringian age of the Magnesian limestones of the north-east of England. We shall therefore take these several areas in the above order.

1. *Midland Area*

Beds which appear to be of Permian age, though no fossils have been found in them, occur in Worcestershire, Staffordshire, and Shropshire, extending as far north as Shifnal, and as far west as Shrewsbury and Alberbury, but not reaching into Denbigh nor into North Staffordshire. The Keele Group of the Upper Coal-measures was formerly regarded as part of them, and so closely are they connected with it, and so little evidence is there of any unconformity, that Mr. Cantrill regards them as an upward continuation of the Coal-measures.¹ He also considers them to be passage beds into the Permian and Trias, but they cannot bridge the whole interval between British Coal-measures and Trias. If they are Carboniferous they might be of Stephanian age, but until this is proved it is better to regard them as Permian and as a

Fig. 107.—SECTION THROUGH THE PERMIAN OF THE ENVILLE DISTRICT IN SHROPSHIRE (E. Hull). Distance about 6 miles.

4. Enville marls
3. The trappoid breccia
2. Conglomerates and sandstones
1. Upper (red) Coal-measures.
F. Fault.
5. The Trias.

Fig. 108. — SECTION FROM THE HALDON HILLS TO NEAR BUDEIGH SALTERTON. Distance about 10 miles, but the width of the Exe estuary is shortened.

- d. Red marls } Permian.
c. Red Sandstones }

possible equivalent of the French Autunian. They can hardly be newer than that.

Where fully developed this Midland Permian consists of three members or divisions as below.

	Feet.
3. Upper (or Enville) marls . . .	100 to 150
2. The Trappoid Breccia . . .	50 to 450
1. The Conglomerate Group . . .	200 to 330
	<hr/> 500 to 800

The thicknesses given are those found in the typical districts of Shropshire and South Stafford. When followed southward the conglomerate group thins out and the marls are overstepped by the Trias, only small patches of the breccia being seen at intervals below the latter.

This Permian Series follows the eastern border of the Coal-measures through Shropshire and Worcester, passing southward on to the Silurian rocks of the Abberley and Malvern Hills. To the eastward it borders the southern half of the South Staffordshire coalfield, but does not extend to its northern extremity.

The Midland Permian, as above restricted, attains its fullest development in Shropshire, and is well exposed in the neighbourhood of Enville on the Staffordshire border (see Fig. 107). Another typical district is that of the Clent Hills in Staffordshire, where the trappoid breccia attains its greatest thickness, but the upper marls are not seen, being presumably concealed by the overstep of the Bunter pebble beds (Trias).

The following account refers more particularly to the Enville district, and has been compiled from a paper by Mr. W. W. King,² who has made a special study of that area.

The Conglomerate Group.—This consists of soft red sandstones and red marls with three interbedded bands of calcareous sandstone and conglomerate, the latter consisting of various pebbles embedded in a sandy matrix, which is cemented by carbonate of lime. The second of these bands is the thickest, being sometimes a massive conglomerate 75 feet thick, and sometimes including lenticular beds of red sandstone with a total thickness of 150 feet. Both conglomerates and sandstones thicken to the north-west and become thinner to the south-west. In the Clent Hills this group is represented by red marls with three bands of sandstone and compact limestone or cornstone, without any conglomerate, but containing small fragments of the older rocks.

The nature of the pebbles varies considerably in different parts of the district. Thus in Shropshire about half the pebbles consist

of dolomitic Silurian limestone like that which occurs in the Abberley Hills, the other half consisting largely of Carboniferous limestone and sandstone. In Staffordshire, especially near Baggeridge on the west, and near Barr on the east side of the coalfield, the majority of the pebbles (60 per cent) are of Carboniferous limestone, most of the remainder consisting of Wenlock limestone. It is thus a remarkable fact that these conglomerates are essentially limestone conglomerates, but contain the debris of various rocks down to and including the Woolhope limestone.

The Trappoid Breccia was so called because it is largely made up of angular blocks of the compact felspathic lavas and tuffs which were formerly known as "traps." They are really rhyolites, hornstones, felspathic tuffs, grits, and agglomerates, and have evidently been derived from pre-Cambrian rocks like those which are known to occur in the Lickey Hills, at Barnt Green near Birmingham, and at Nuneaton. With these are associated many fragments of Llandovery sandstone and a few of Woolhope limestone.

Mr. King remarks that the difference between the assemblage of rocks found in the conglomerates and that in the breccia may be explained on the supposition that during the accumulation of the former valleys in the adjacent country were being cut down through the Carboniferous and Silurian to the Woolhope limestone, while in the later epoch erosion was continued through the Llandovery Beds, and deep into the underlying Archæan rocks. It is also possible that the materials of the two deposits were brought from different directions.

Another remarkable fact connected with this breccia is that many of the blocks are very large, and that some of them are scratched or striated, the striations resembling those of glaciated stones, so that Sir A. Ramsay was led to infer the existence of glaciers and glacial moraines to account for them. This view, however, has not been sustained, and the striations are now attributed to the grinding of rock-fragments against one another during the many subsequent earth-movements which they have experienced.

This breccia can be traced southward through Worcestershire, where it is often called the Haffield breccia, from its occurrence on Haffield Hill near Great Malvern. This is its most southerly outlier, but others occur on the Abberley Hills, resting on Silurian and Old Red Sandstone.

The Enville marls are only found in Shropshire, and are not seen farther south than Enville, though they doubtless extend much farther southward beneath the Trias. They include a band of Breccia which near Enville is 50 feet thick, but thins out to

the north-west, while the thickness of marl increases in that direction. It is clear, therefore, that the materials of this breccia, as of the main mass, came from the south and south-east.

In Leicestershire there are a few small but interesting deposits of Permian age, which have been carefully studied and described by Dr. H. T. Brown³ and Professor Bonney.⁴ They consist of grey breccias, grey sandstones, and red marls, not more than 60 feet thick in Leicester, but as much as 200 at Polesworth in North Warwick. The breccias thicken to the south and the marls to the north, and their thickness may originally have been greater, as they are overlain unconformably by the Trias. The pebbles in the breccias consist of the following kinds of rocks :—

(1) The larger number (about 60 per cent) are felspathic grits or quartzites, derived from the Cambrian quartzites, but differing slightly from those exposed at Hartshill.

(2) Gritty slates from the same series, averaging 17 per cent.

(3) Flinty slates and argillites, probably Charnwood rocks.

(4) Volcanic rocks, some being felsites and andesites from the pre-Cambrian (Caldecote) Series, some of a rock which may have come from Charnwood, and diorites like those in the Cambrian near Nuneaton.

(5) Fragments of Carboniferous grits, ironstones, and hæmatite ; but pebbles of Carboniferous limestone are rare, except at Polesworth.

In most of the exposed breccias over 80 per cent of the fragments come from the Cambrian quartzite series, and Dr. Brown shows that they have probably been derived from a buried ridge of these rocks which underlies Market Bosworth and runs parallel to the well-known Hartshill ridge. This buried ridge appears to be a faulted anticline, and so exact is the parallelism between these ridges and the principal faults of the Leicestershire coalfield that they may safely be attributed to the same period of earth-movement. These faults are known to be post-Carboniferous, and the undisturbed way in which the breccias lie, bridging over the faults, makes it very probable that they are of Permian age.

The view that these are terrestrial deposits of early Permian age will account for their proximity to the different set of deposits near Nottingham which belong to a late epoch in Permian time.

2. *Devon and Somerset Area*

This area is taken next because its Permian rocks have a strong resemblance to the Saxonian facies, and especially to the Rothliegende of the Hunsrück district between Treves and Bingen, as pointed

out by Herr von Reinach.⁵ The Devonshire Series is much thicker than that of the Midlands, but thins northward and appears to have been formed in an isolated lake basin which persisted throughout both Permian and Triassic times till it was merged into a larger inland sea (see Fig. 64, p. 201).

The succession, where most fully developed in South Devon near Teignmouth, Dawlish, and Exeter, is shown in Fig. 108, and has been described by Mr. Ussher⁶ as follows :—

	Feet.
Red marls with occasional sandstones (? Permian)	about 500
Red sandstones	250 to 400
Red conglomerate and breccia	900 to 1000
Dark-red Watcombe clays (local)	100 to 150

Maximum about 2000

The Watcombe clays occupy some little space north of Torquay by Watcombe, Barton, and Dacombe, and they reappear between Teignmouth and Bishopsteignton. They consist of fine dark-red clay which has long been used for the manufacture of terra-cotta ware, and also for the making of tiles and hard bricks. The deposit seems to fill a broad hollow in the Palæozoic rocks, for it is overlapped by the breccias both to the south and north as well as westward.

The overlapping breccias consist in the lower part of conglomerate and breccia, in which fragments of Devonian limestone are abundant. These beds are well exposed in the fine cliffs between Babbacombe and the estuary of the Teign, and their thickness is estimated at from 400 to 500 feet, but the frequent faults make the estimate uncertain. The higher breccias differ in containing a larger proportion of derived volcanic rocks, chiefly of a peculiar red quartz-porphry, and some of the boulders are of large size. This portion has a thickness of from 500 to 600 feet, so that the total thickness of breccia is about 1000. These breccias stretch northward beneath the Haldon Hills to Dunchideock and Ide.

South-west of Exeter there are sheets of trachytic and andesitic lava at their base, indicating the contemporaneous existence of volcanoes, but the material of these lavas is quite different from that of the blocks in the breccia, which must have belonged to another set of volcanic eruptions, probably of rather earlier date.

A similar breccia is found in the Crediton valley forming a long tongue which runs westward across the valley of the Tawe, and has an outlier at Hatherleigh (see Fig. 64, p. 201). North of Silverton the breccias pass into loose gravels which contain a different assemblage of stones, evidently derived from rocks to the northward, and the whole series becomes thinner as it is traced into Somerset.

Near Dawlish and Exeter the breccias graduate upward into sandstones, and these are succeeded by red marls with lenticular beds of sandstone, which seem to be an upward continuation of the series. These marls may be of Thuringian age, and consequently homotaxial equivalents of the Magnesian Limestone Series described below, though never actually connected with that series.

How far these Permian rocks extend eastward beneath the Trias and newer strata we have no means of knowing, but they certainly had a considerable extension southwards, for patches of them occur between Bolt Head and Plymouth, and fragments of red breccia have been dredged from many parts of the sea-floor south-east of Cornwall, in such fresh condition as to indicate the existence of submarine reefs of this rock.

3. North-Eastern Area

In this area we have undoubted representatives of the Thuringian stage in the form of fossiliferous magnesian limestones with intercalated red marls. The outcrop of this series is shown on the map (Fig. 87), from which it will be seen that although the strike of the Permian Beds is at first nearly in accordance with that of the underlying Coal-measures, yet they do not participate in the anticlinal flexures which give an east and west strike to these measures in South Durham. Near the valley of the Tees the Permian oversteps the Coal-measures, and rests first on the Millstone grit, and then on Carboniferous limestones. Farther south it again crosses the Millstone grit onto the Coal-measures of Yorkshire and Nottingham, but it is everywhere unconformable to the latter.

There is a marked lithological change in this series as it is followed from north to south. In Northumberland and Durham it is composed almost entirely of magnesian limestones (*i.e.* dolomites), and the complete succession of beds, according to Dr. Woolacott's⁷ recent examination of them, is as follows:—

	Feet.
Red marls with thin limestones and beds of salt	500
Magnesian limestone. { Upper limestones, bedded for the upper 100 feet, concretionary for some 200 feet, with a bed of flexible limestone at the base (10 feet)	300
{ Middle limestones—bedded yellow limestones on the coast replaced westward by compact fossiliferous limestones, both often much altered and brecciated	150 to 300
{ Lower bedded brown limestones	40 to 200
The Marl Slate (a brown calcareous shale)	3
The Yellow sands (soft and without fossils)	0 to 150

Total about 1200

The fauna is restricted (about 140 species) and peculiarly distributed; fossils are most abundant in the Middle limestones, which seem to have formed a shell bank, and only a few Lamelli-branches and Gastropods survive into the Upper Beds. Fish remains occur at two horizons—the Marl Slate and the flexible limestones, and in the beds just above these deposits. *Productus horridus* is characteristic of the Lower and Middle limestones. For other common fossils see Fig. 105.

In Yorkshire, near Pontefract and elsewhere, the limestones are thinner, but the marl slates are thicker than in Durham, and sometimes rest on white and yellow sands, which in turn rest on an eroded surface of red marls and sandstones belonging to the Upper Coal-measures (see p. 298). In South Yorkshire the succession may be summarised as follows:—

	Feet.
Upper red marls	50
Upper (Brotherton) limestone	50 to 120
Middle red marls	30 to 50
Middle limestone, thick-bedded	150 to 200
Lower limestone	about 120
Blue limestones and shales	5 to 15
Quicksands and breccia	10 to 20

From 430 to 570

Traced southward into Nottinghamshire, the Upper limestone thins southward and is at the same time overlapped by the Trias, so that the thickness of the Permian at its outcrop is very much diminished, being as follows:—

	Feet.
Middle marls and sandstones	20 to 30
Magnesian limestone (lower)	60 to 70
Marl slates	30 to 50

Southward near Kimberley the limestone passes into a yellow calcareous sandstone about 30 feet thick, resting on 15 to 20 feet of shaly marl, with a few feet of coarse breccia at the base. This change and diminution in thickness is evidently an indication that we are in this direction approaching the southern shore of the Permian Sea. The breccia contains angular fragments of sandstone and shale derived from the Coal-measures on which it rests, together with pebbles of slate, quartz, and quartzite, and it is not unlikely that these were derived from a northerly prolongation or the Charnwood rocks.

From borings made in search of coal near Haxey in Lincolnshire, and near Newark on the eastern border of Notts, it is known that the Permian limestones and marls exist in full force below these places. At Haxey the Permian was entered at 1183 from

the surface, and its base is supposed to be at 1728, but may be 68 feet lower. The beds traversed were:—

	Feet.
Upper marls with gypsum	58
Upper limestones	84
Middle marls with gypsum	134
Lower limestones	270
Doubtful beds (sandstones)	68

At Newark it consisted mainly of magnesian limestones, with 118 feet of red marl above them, the total being 519 feet, and the base is there clearly marked by a bed of grit and breccia.

4. North-Western Area and Ireland

On the western side of the Pennine ranges only a few isolated tracts of Permian strata are found, but as they include fossiliferous magnesian limestones, there can be little doubt that they were originally connected with the eastern area and are remnants of an extensive series of deposits which covered a large part of Northern England and spread across the space now occupied by the Irish Sea into the north of Ireland, where patches still exist as far west as Tyrone.

Beginning with the southern part of this area a strip of Permian is found near Stockport and Manchester, consisting of:—

	Feet.
2. Marls and limestones with marine fossils	230
1. Soft red and variegated sandstones	from 300 to 1000

Fossils found in the upper beds at Fallowfield include *Pleurophorus costatus*, *Schizodus Schlotheimi*, *Bakevellia antiqua*, *Aucella Hausmanni*, and *Turbo helycinus*.

Still farther north several small outlying patches of Permian have been found, one east of Preston, another near Clitheroe, where it lies on Carboniferous limestone, and a third rather larger area in the centre of the Burton coalfield; these occurrences show the beds to be completely unconformable to the Carboniferous rocks, just as on the eastern side of the Pennine anticline.

The largest Permian tract is that on the western side of the Vale of Eden, extending from Kirkby Stephen in Westmoreland by Appleby and Penrith to within about 3 miles of Carlisle, where it is faulted down below the Triassic sandstones. Here the lowest member of the series is a bright-red sandstone, known as the Penrith sandstone and having a maximum thickness of 1500 feet.

In the southern part of the Vale this red sandstone includes

beds of breccia and conglomerate (locally called brockram) consisting of fragments of limestone embedded in a sandy matrix. These breccias are thickest in the south-east, being sometimes over 100 feet thick, and they thin out northwards till at and north of Penrith they have quite disappeared, and only red Penrith sandstone remains.

The surfaces of some of the sandstone beds bear numerous foot-prints, some of which seem to be tracks of Labyrinthodonts or other amphibians, and some of reptiles (the lacertoid prints).

Above these sandstones are shales and magnesian limestones; at Hilton Beck, near Appleby, the former are about 40 feet thick and contain remains of the following plants:—*Ullmannia Bronni*, *U. selaginoides*, *Alethopteris Goepperti*, *Sphenopteris Naumanni*, *N. dichotoma*, *Cardiocarpum triangulare*, and *Odontopteris sp.* These

Fig. 100.—SECTION THROUGH THE PERMIAN BEDS NEAR PENRITH (Harkness).

A. Red sandstone.	C. Magnesian limestone.	E. Carboniferous.
B. Red shale.	D. Penrith sandstone.	F. Ordovician.

shales thin out northwards, but the magnesian limestone extends rather farther; where thickest there is only 25 feet of it, but probably it is only the base of a much thicker mass since removed or else concealed by the unconformity of the Trias.

Other small patches of these Permian deposits occur in the west of Cumberland, as on the coast at St. Bees Head, and inland at Egremont and Arlecdon. It should also be mentioned that the Permian Series above described is everywhere overlain by a set of red shales and marls with beds of gypsum, and by some these are classed as Permian, but Mr. Goodchild has pointed out that they rest sometimes on the limestone, sometimes on the Hilton shales, and sometimes on Penrith sandstones, so that there is a decided unconformity, and the marls should be regarded as the base of the Trias.

Permian Beds are found also in the Isle of Man and again at three places in Ireland, one at Cultra on Belfast Lough, another

near Ardrea in Tyrone, at both of which they include fossiliferous magnesian limestones; at the third place (Armagh) there are only boulder-beds and breccia resting on Carboniferous limestone.

5. Scotland

In Dumfries and Ayrshire there are tracts of bright-red sandstone which have much resemblance to the Penrith sandstone, but till recently no evidence for their identity was forthcoming, and consequently they were regarded by some as belonging to the Trias, and were so classed in the last edition of this book. Mr. G. Hickling,⁸ however, has compared the Reptilian footprints of the Dumfries sandstones with those of the Penrith Beds, and finds that though not identical they are similar, and differ from those on Triassic sandstones, and further that two of the types seem to be identical with prints in the Permian sandstone of Mansfield (Nottingham).

Dumfries.—In this district the three largest tracts are (1) one extending from the Solway Firth by the mouth of the Nith to and beyond the town of Dumfries, (2) round Lochmaben in Annandale, and (3) round Thornhill in Nithsdale. Professor Harkness was of opinion that the general succession of the beds near Dumfries and Lochmaben is as follows:—

	Feet.
4. Thin-bedded sandstones with beds of clay . . .	300
3. Hard massive breccias and conglomerate . . .	300
2. Soft red current-bedded sandstones }	
1. Coarse sandstones and breccias }	500

The breccias consist of angular blocks and fragments of various Palæozoic rocks, with some of granite and other igneous rocks, embedded in red sand. The lower sandstones are brick-red in colour, frequently flaggy and divided by thin seams of dark-red clay, and their surfaces often bear the footprints of Labyrinthodont and other reptiles. Such footprints were first described by Professor Buckland from specimens found in the quarries on Corncockle Moor near Lochmaben, but they are equally common near Dumfries; they also occur in the upper sandstones, the beds of which are separated by rather thicker layers of clay.

In the Thornhill basin farther north there are no breccias, and the greater part of the tract consists of brick-red sandstone, but in the northern part lava-flows and volcanic detritus are interstratified with the lowermost sandstones. The higher sandstones contain beds of shale and clay, and seem comparable to the higher beds near Dumfries.

Ayrshire.—In the centre of the Ayrshire coalfield near Mauchline lies a pear-shaped area, occupied by rocks similar to those of Thornhill (see Fig. 110), and associated with the volcanic breccias of this district are some beds of a purple sandy limestone, but no fossils have been found in them.

The igneous zone consists of a number of lava-flows which mark successive eruptions, and have probably proceeded from more than one vent, for though they are all of a basic character they vary much in lithological composition. Some of them are basalts, others are magnetite-felspar rocks, while the rock of Mauchline Hill is a picrite composed chiefly of olivine and augite. Magnetite is prevalent in all of them, and its oxidation has given them a red colour, on which account they have been described as "porphyrites."

Besides these interbedded volcanic rocks there is other evidence of the number and activity of the volcanoes. Outside the existing tracts of Trias the Coal-measures are pierced by numerous large

Fig. 110.—SECTION THROUGH THE PERMIAN BASIN OF AYRSHIRE (Geikie).

f. Basaltic dyke.
c. Volcanic necks.

d. Red sandstones.
c. Volcanic tuffs.

b. Lava-flows.
a. Carboniferous rocks.

pipes filled with a coarse unstratified agglomerate, and usually appearing at the surface as small rounded hills or hillocks. Sometimes the agglomerate includes a core or column of lava, and the coal-seams in their neighbourhood are often charred or altered into columnar coke. There can be little doubt that these columns or necks are some of the vents through which the volcanic materials were ejected. The necks are especially numerous in the Dalmelington coalfield, but they occur also in Renfrewshire and Lanarkshire, piercing the highest Coal-measures in those counties.

Moray.—The only other area where Permian Beds have been recognised is in Moray, one small tract lying to the east of the town of Elgin and another near Cummingstone. The rock is a coarse red false-bedded sandstone, consisting of rounded quartz-grains, and containing sand-worn pebbles; the total thickness of the beds, according to Mr. D. M. S. Watson,⁹ being from 400 to 500 feet. Apparently it was formed in a depression or lake in a wind-swept desert region, for near Elgin it has yielded bones of the characteristic Dicynodont reptiles—*Gordonia*, *Elginia*, and *Geikia*. The similar sandstone near Cummingstone has not yielded bones, but shows footprints which closely resemble some at Mansfeld in Notts,

and in the Permian of Thuringia. Mr. Watson suggests that they may have been made by *Gordonia*.

D. CONTINENTAL PERMIAN STRATA

1. *France*

Small tracts of Permian rocks occur at many places round the great Central Plateau of France (see map, Fig. 102), most of them abutting against the ancient rocks of this plateau, and passing outward beneath the newer deposits which surround it. They appear to belong to two separate areas of deposition, the one group on the north extending from a point south of Berry by Buxière and Moulins, and reappearing on the Morvan near Autun where there are two basins or troughs. The other area lay to the south and south-west of the plateau, patches of its deposits occurring near Brive, near Rodez in Aveyron, near Carmaux in the Tarn, and again from Broquies in a long strip to Grassessies on the Montagne Noire.

The beds of the Autun basin form the type of the *Autunian* stage. They overlie the Stephanian measures, and the lowest set of beds which are classed as Autunian are really passage-beds, containing a flora like that of the beds below, except that it includes *Walchia piniformis* and *Callipteris conferta*. These beds are about 1300 feet thick and are entirely of freshwater origin, consisting of sandstones and bituminous shales, with beds of magnesian limestone full of Cyprids; and they form the zone of Igornay.

They are succeeded by another group of similar rocks (zone of Muse) with two valuable beds of oil-shale, and a more typical Permian flora. Lastly there is an upper stage (zone of Millery) about 1500 feet thick, consisting of shales and thin coal-seams, one of the latter being the famous Boghead coal. The whole series is about 4000 feet.

This Autunian Series has yielded a rich harvest of vertebrate remains; the Amphibia have been described by Gaudry, and include *Protriton petrolei*, *Pleuroneura Pellati*, *Actinodon Froissardi*, and *Stereorachis dominans*. Fish are numerous, and silicified stems of tree-ferns (*Psaronius*) are common in the upper beds.

At Bourbon and Buxière the series is not so thick, and consists more largely of felspathic sandstones derived from the erosion of the neighbouring granitic and gneissic rocks. The lowest beds, however, include bands of oil-shale and black limestone, and doubtless belong to the Autunian lake-basin.

Wherever the summit of the Autunian is exposed, it is over-

lain by sandstones of Saxonian age, grey in the lower part, red and mottled in the upper part, with a combined thickness of about 1600 feet. Nothing comparable with the Zechstein or Magnesian Limestone Series has been found in any part of France.

Of the more southern Permian facies that of Aveyron and Lodève may be taken as typical, the succession in that district being:—

Saxonian,	{	Fine sandstones and black shales passing down into red
1500 feet	{	sandstones and marls with <i>Walchia</i> and <i>Callipteris</i> .
Autunian,	{	Lodève slates with plant remains.
500 feet	{	Black shales with <i>Palæoniscus</i> .
	{	Sandstones, shales, and a basal conglomerate.

The small basin of Littry in Calvados deserves mention because of its proximity to England, and because the deposits which there overlie the Stephanian are referred by French geologists to the Autunian. They consist of red sandstone, succeeded by a bed of magnesian limestone and shales from which remains of *Palæoniscus* and *Amblypterus* have been obtained.

2. Germany

Permian rocks occupy much larger areas in Germany than they do in France or Britain, and two of these areas may be specially noticed, *i.e.* that of the Sarre district and that of Saxony and Thuringia.

Sarre Valley.—The most extensive area of the Lower Rothliegende or Autunian is that of the Sarre and Nahe district, where they occupy a wide space between the Devonian of the Hunsrück on the north and the outcrop of the Trias on the south. Here, as shown in Fig. 103, the Ottweiler Beds are overlain conformably by the Cusel Beds, consisting of red and grey sandstones and shales with thin layers of coal, and as at Autun they have a Carboniferous flora to which a Permian aspect is imparted by the presence of *Walchia piniformis*, *Callipteris conferta*, and *Calamites gigas*.

The succeeding Lebach Group comprises sandstones at the base, overlain by shales containing ironstone nodules in which are fish remains, scales of *Archegosaurus* and the Crustacean *Gamponyx*. Interbedded with these sediments are sheets of porphyritic andesite and melaphyr.

The *Saxonian* is represented by a series of red conglomerates, sandstones, and shales, the materials of which have been mainly derived from the detrition of the neighbouring Devonian and Carboniferous rocks. These "Upper Rothliegendes" have a much wider extension northward and eastward than the Autunian, overlapping the latter on to the older rocks.

Central Germany.—In the central part of Germany (Thuringia and Saxony) the passage-beds are absent, and the Permian is more or less unconformable to the Carboniferous; but the Lebach Group is well represented, and has yielded many amphibian remains, *e.g.* of *Branchiosaurus*, *Archegosaurus*, and *Pelosaurus*. Its chief development is in the Erzgebirge basin near Chemnitz and Zwickau, where it consists of coal-bearing beds, with the usual plants in the lower part, together with beds of volcanic tuff and sheets of trachytic lava; and these beds are overlain by a set of red breccias, conglomerates, and sandstones, largely composed of the debris of contemporaneous volcanic rocks.

The Saxonian of this region is a thick mass of conglomerates, sandstones, and marls, the predominant colour of which is red or reddish brown. These beds have a thickness of about 1600 feet in Saxony and nearly 2000 in Thuringia. No fossils occur in them except plant remains and the footprints of reptiles and amphibians,

Fig. 111.—SECTION THROUGH THE ERZGEBIRGE BASIN (by Sievert).

v. Sandstones and tuffs.
P, t. Lavas and tuffs.

r. Lebach Beds.
c. Coal-measures.

s. Silurian.
p. Archæan.

so that the whole formation up to the top of the Saxonian appears to be of lacustrine and terrestrial origin.

The succeeding division is largely marine, and includes the Zechstein limestone, but as that is really only a small portion of it the name *Thuringian* is a much better one. This group of beds occupies a considerable area in Central Germany, spreading round the mountain ranges of the Thuringerwald, the Frankenwald, the Reisingebirge, and the Harz, and passing everywhere below the overlapping Trias and Jurassic strata. In its typical development it is a series of limestones and shales of no great thickness, from 400 to 500 feet, but in certain localities it is expanded by the intercalation of enormous masses of gypsum and rock-salt. In the Mansfeld district it has the following components:—

Upper	{ Red clay and gypsum.
200 feet	{ Clays with lenticular beds of limestone.
Middle	{ Dark bituminous limestone and shale.
150 feet	{ Gypsum and dolomitic breccia.
Lower	{ Magnesian limestone (the Zechstein).
200 feet	{ Bituminous shale (Kupferschiefer).
	{ Calcareous sandstone and conglomerate.

The similarity between this series and the "Magnesian limestone" of England will at once be apparent. The layer of copper-bearing shale which overlies the basement beds is only about 2 feet thick, and is the analogue, if not the actual continuation, of our "Marl slate"; it yields similar fish remains (*Platysomus gibbosus* and *Palaeoniscus Frieslebeni* being common species), with scales of *Proterosaurus*, and occasionally star-fish and Brachiopods, which clearly indicate the invasion of the area by an outer sea.

The fossils of the Zechstein are similar to those of the English limestones, many of the species being the same, and the only Cephalopoda being a few species of *Orthoceras* and *Nautilus*. Some of the beds are almost entirely composed of Bryozoa, species of *Fenestella*, *Acanthocladia*, and *Phyllopora*, and these beds are called "Bryozoon-reefs" by German geologists, a misleading term suggesting reef-formation which does not exist, for they are merely lenticular beds of limestone resulting from local Bryozoon growths, like the crinoidal and coralliferous limestones of Devonian and Silurian age.

In Hesse the composition of the Thuringian differs little from the above, but north of the Harz district thick beds of gypsum and rock-salt come in, which are worked at Stassfurt, Egeln, Vienenburg, and other places. The rock-salt is sometimes over 1000 feet thick, and at Sperenberg (south of Berlin) it is over 3000.

The typical Zechstein facies of the Thuringian extends also eastward into Silesia (north of Gatz).

3. Russia

In Russia, as already stated, the Permian is largely marine, but the limestones with marine fossils are often interbedded with sandstones, shales, and marls of estuarine or lacustrine origin. According to Nikitin, in the typical district of the ancient kingdom of Permia—now the provinces of Perm, Samara, and Ufa—the series is divisible as follows:—¹⁰

Thuringian	{	Red marly sandstone.
		Red marly limestone.
		Grey limestones and marly sandstones.
Kostromian	{	Red sandy marls (marine fossils).
		Marly limestone without fossils.
Artinskian	{	Clays with gypsum and beds of limestone.
		Dolomitic limestones with Permian fossils.
		Dolomitic limestones (Perno-Carboniferous).

The stages were not established when Nikitin wrote, but I have bracketed his subdivisions to show how they probably correspond with the grouping made in the Ural region.

On the western slopes of the Urals the *Fusulina* limestone of the Uralian is succeeded by a series of sandstones, limestones, and

marls, partly lacustrine and partly marine, the fauna including some survivals from the Carboniferous, such as *Productus cora*, *P. punctatus*, and a species of *Phillipsia*, but associated with a new and peculiar set of Ammonoids, *i.e.* *Medlicottia*, *Popanoceras*, *Agathiceras*, and *Thalassiceras*. The plant remains again are chiefly Permian forms, including *Calamites gigas* and *Callipteris conferta*, with several species of *Walchia* and *Ulmannia*. This set of beds was called the Artinskian stage by Karpinsky in 1874, and it is clearly a marine representative of the western Autunian.

In the same area, overlying the Artinskian, is Sibertzew's¹¹ *Kosstroma stage*, which is evidently the equivalent of the Saxonian. It presents two facies, the one of marls and sandstones (some grey and some red), containing plant remains with *Carbonicola* and bones of *Palæoniscus* and *Archegosaurus*; the other consisting of various kinds of limestone (oolitic, compact, marly, etc.), with a marine fauna, including *Productus Cancrini*, *Athyris Roissyi*, *Dielasma elongatum*, and *Bakevella parva*.

Still higher are limestones with many Zechstein fossils, but it is noteworthy that *Productus Cancrini* takes the place of *P. horridus*, and *Strophalosia horrescens* that of *S. Goldfussi*. These are overlain by red sandy marls, containing freshwater Unionidæ (*Naiadites* and *Palæomutela*), which Nikitin proposed to call the "Tartarian stage." If adopted as an equivalent for the whole of the Russian Thuringian the name might be useful.

In Vologda (Northern Russia), near the sources of the Little Dwina and Suchona, certain marls and sandstones belonging to the upper stage have acquired importance from Amalitsky's discovery in them of the remains of many reptiles—*Pareiasaurus*, *Dicynodon*, *Rhopalodon*, *Elginia*, *Gordonia*, and others, associated with many Unionidæ (*Palæanodon*, *Palæomutela*, *Oligodon*, *Carbonicola*, etc.), and a flora of mixed Asiatic and European types, *i.e.* species of *Glossopteris* and *Gangamopteris*, with *Callipteris*, *Teniopteris*, *Schizoneura*, etc.¹²

E. HISTORY OF THE PERIOD

From the stratigraphical facts, which have been summarised in the preceding pages, we may gather that the Permian period was a natural continuation of the Carboniferous, and that the earliest Permian sediments were accumulated in the same areas and under almost the same physical conditions as those of the preceding Stephanian epoch.

The western half of the European area was clearly part of a large continent which extended westward far into the Atlantic

region, and eastward to the borders of Russia. The northern part of this continent seems to have been a hilly and mountainous region, wherein little deposition of any kind took place until quite the later part of the period. Across the centre of the continent, and traversing its whole breadth from west to east, ran the great Armorican and Hercynian ranges, probably consisting of many mountain ranges with intervening valley-like depressions. To the south of these ranges the country sank to lower levels, and here there were large lakes and swampy depressions in which the Autunian deposits were formed. In these tracts and along the valleys of the rivers which carried the rainfall from the hills to the lower lands grew a rank flora of Carboniferous aspect; and here dwelt many kinds of Amphibia, both small and large, and some primitive Reptilia, the larger of which doubtless fed on the fish which inhabited the lakes and rivers. Such is the picture that we may form of Europe in early Permian time.

The nature of the Saxonian deposits, and the great contrast which they present to the underlying Autunian, indicates that a great change took place; and we may infer that this was caused by a general uplift of the whole continental region, whereby the lakes and marshes were drained, and its lower levels were converted into broad plains separated by ranges of hills and mountains. This change produced a corresponding alteration in the climate of the country, so that its more southern parts passed from a condition of great humidity with mild winters to one of comparative dryness and very cold winters.

Great terrestrial erosion and detrition was another result of the upheaval, leading to the production of the thick deposits of sandstone and conglomerate which form the chief Saxonian accumulations, and to the formation of breccias round the mountain ranges. These breccias are in themselves strong evidence of peculiar climatic conditions. They have been compared, both by Mr. R. D. Oldham and by Professor T. G. Bonney, with the fringes of angular gravel and breccia which flank the hill ranges of Persia and other parts of Central Asia at the present day.

Referring to the Permian breccias Professor Bonney¹³ remarks that the resemblance above mentioned suggests that the climate, both of Germany and Britain, was also similar to that of modern Persia, hot in summer but cold in winter. He also quotes Professor Garwood as pointing out that the distance to which some of the large blocks have been transported can be explained on the supposition of snow-slopes, without bringing in the agency of glaciers as some have thought necessary. Professor Garwood had observed in Spitzbergen that the talus-slopes on the hillsides were deeply

covered by snow in the winter, and that fragments falling on this snow-slope slide down to its outer edge. This process is repeated year by year, so that the talus fringe is continually being extended, and blocks of large size are conveyed to a much greater distance from their sources than would be possible without the snow-slope.

Another accompaniment of this Permian upheaval was the outbreak of volcanic action and the establishment of numerous volcanoes, from which frequent eruptions of lavas and ashes took place. Nor are there wanting evidences of earthquakes, especially in Devonshire, where round Brixham and Torbay the Devonian limestones are riven by fissures from a few inches to 3 feet in width, and these are filled with red sandstone similar to the Permian sandstones, of which patches still remain on the surface of the limestone plateau.

This epoch of high elevation may have lasted for a long time, but at length another change took place; volcanic activity ceased, and as so often happens in such cases a general sinking in and subsidence ensued. Some of the great plains on which the red sandstones and breccias had been accumulated sank below sea-level, and were invaded by the Eastern Sea, becoming a large gulf or land-locked "Mediterranean" sea in which deposits of dolomitic limestone, shale, and marl were formed.

Toward the close of the period, however, this inland sea became isolated, probably by local warping and other irregular crust-movements, so that it was cut off from the outer sea and converted into a great salt lake like the Caspian Sea of the present time. From time to time during dry seasons portions of this sea were dried up, and the salts in solution were precipitated to form the thick masses of gypsum and rock-salt which are such conspicuous members of the highest Permian deposits.

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CHAPTER XII

THE TRIASSIC SYSTEM

WITH the close of the Permian period the last remnants of Palæozoic life became extinct in the British area, and when after a long continental period the western and northern parts of Europe were again submerged beneath the sea, the waters were tenanted by a very different set of generic forms. The Palæozoic Groups of Cystid and Blastoid Echinoderms, Rugose Corals, Eurypterids, Trilobites, Goniates, and most of the Palæozoic genera of Nautiloidea had died out, their place being taken by the Euechinoids, Aporose Corals, Siphonate Gastropods, and Cephalopods of the Ammonite and Belemnite type; many orders of Reptiles appear for the first time, and the earliest Mammal yet known occurs in the upper beds of the Trias.

The fish of the Triassic and Jurassic periods also exhibit remarkable changes and developments. The Rhizodont Crossopterygian fishes of the Devonian and Carboniferous, and the heterocercal Palæoniscids of Carboniferous and Permian time now become scarce; while a new type of fish (the *Protospondyli*) with a nearly homocercal tail and a more bony endoskeleton having a tendency to form vertebræ, make their appearance and lead up to the completely vertebrate Teleosteans.

Even where a continuous series of marine deposits bridges over the gap in the history of marine life which exists in Northern Europe we find that the above remarks are still practically true, the only exception being the existence of a few Gastropod genera and a few species of *Orthoceras* in the Trias of the Alps. For reasons which cannot yet be fully explained the Triassic period seems to have been one of rapid organic change and development, and in no class is this more beautifully illustrated than in that of the Cephalopoda, the Alpine Trias presenting us with a remarkable assemblage of genera which practically connect the Palæozoic Gonia-

tites with the Ammonites which are so characteristic of the Mesozoic periods.

A similar dying out of old forms and a rapid spread of newer types took place in the vegetable world. The Palæozoic Lycopodiales—*Lepidodendron*, *Bothrodendron*, and *Stigmaria*—have now all disappeared, while the Cycads which appeared in Permian time now become much more numerous, and are associated with the coniferous *Voltzia*. Among ferns, though some of them have been referred to *Pecopteris* and *Neuropteris*, it is very doubtful whether any belong to these Palæozoic genera; most of them are rather referable to the more recently established genera *Chladophlebis* and *Todites*. Many other new genera make their appearance.

Here, therefore, at the base of the Trias is drawn the line between the Palæozoic and Neozoic eras, and here begins that division of Neozoic time which is often called the *Mesozoic*. It must not be supposed, however, that there is any great break between the two series of formations, for though there is a partial break in Britain, there is complete conformity between the Permian and the Trias, with a passage from one to the other in the Alpine region, and in most parts of Germany.

THE TRIASSIC SYSTEM

A. NOMENCLATURE AND CLASSIFICATION

The Triassic System resembles the Devonian System in that it presents us with two very different facies, (1) a terrestrial and lacustrine facies formed within the limits of a large continent, and (2) a marine facies of the usual kind. The first forms the upper part of what used to be known as the New Red Sandstone (see p. 6), but was called the *Trias* by von Alberti in 1834 on account of its obvious tripartite arrangement in Germany. In England, however, it has only two parts, and these are both of terrestrial or lacustrine origin; in Germany these persist, but the middle beds are limestones containing marine fossils, and consequently there are three series, which have received the following names:—

3. The Keuper (red marls and sandstones).
2. The Muschelkalk (marine limestones).
1. The Bunter (variegated marls and sandstones).

For the normal marine facies of the Trias we must go to the Alps, and the student cannot understand the true relations of the Triassic System to those which precede and follow it until he has learnt something about the important marine facies of the forma-

tion which exists in the Tyrol and extends throughout Southern Europe.

Moreover, this marine facies has a wide extension over other parts of the world; it spreads through Southern Europe from Spain to Hungary and the Balkans; it is found in Turkestan, Central Asia, and the Himalayas, and a similar marine Triassic System occurs in Siberia, Japan, North America, and again southward in Columbia, Peru, New Zealand, and Australia. In South Africa, in South India, and in Argentina red sandstones with reptilian remains are found, and these regions seem to have formed part of other Triassic continents. In this volume, however, it is only possible to give a brief account of the European Trias.

The name Trias, as will be seen, is not a good one, being really applicable to the German facies only, which is a limited and exceptional one. A nomenclature capable of wider application will doubtless be eventually proposed, and must, of course, be based on the pelagic development of the system. From the recent work of Mojsissovics, Waagen, and Diener on the distribution of the fossils in the pelagic facies, it appears that the system falls more naturally into two great divisions, a lower and an upper, each of which is again divisible into two series.

B. LIFE OF THE PERIOD

1. *The Marine Fauna*

The fauna of the Alpine and Tyrolian Trias, though consisting mainly of Neozoic forms of life, yet includes some survivors of Palæozoic types; the proportion of species belonging to genera which are essentially Palæozoic being stated as only one-tenth of the total number of species composing the fauna.

The Cephalopoda are a remarkable assemblage. A single species of *Orthoceras* with some of *Temnocheilus* and *Pleuromutilus* connect it with Palæozoic faunas, while the genus *Nautilus* (as now restricted) makes its first appearance. The Ammonoidea, however, are the dominant forms, and include many genera with nearly simple lobes and saddles, such as *Ceratites*, *Lobites*, *Tirolites*, *Trachyceras*, *Tropites*, as well as genera with more complex lobes, such as *Arcestes*, *Cladiscites*, *Ptychites*, *Pinacoceras*, *Phylloceras*, *Rhacophyllites*, and *Megaphyllites*. Dibranchiate Cephalopoda make their first appearance and are represented by precursors of the Belemnitidæ in *Aulacoceras* and *Atractites*.

Gastropoda are abundant, and include representatives of the Palæozoic genera *Murchisonia*, *Loxonema*, *Naticopsis*, and *Euom-*

phalus, with the Neozoic types of *Trochus*, *Turritella*, *Scalaria*, *Cœlostylina*, *Cerithium*, and *Pseudomelania*, as well as peculiar forms which have been named *Naticella*, *Chilocyclus*, and *Ptychostoma*.

Of Lamellibranchs *Posidonomya*, *Megalodon*, and *Myophoria* (which is probably inseparable from *Schizodus*) connect the fauna with Palæozoic life, while certain genera are especially Triassic, such as *Halobia* (= *Daonella*), *Monotis*, *Cassianella*, *Trigonodus*, and *Anoplophora*. There are many representatives of *Pteria*, *Gervillia* (*Hærnesia*), *Pecten*, and *Lima*; and the following genera make their first appearance, *Velopecten*, *Plicatula*, *Mytilus*, *Lucina*, *Sphæriola*, *Cardita*, *Palæocardita*, *Unicardium*, *Protocardium*, and *Homomya*.

The Brachiopoda include the last survivors of the ancient genus *Spiriferina*, with some specially Triassic forms, such as *Koninckina*, *Thecospira*, and the Athyroids which Bittner has separated under the names of *Tetractinella* and *Pentactinella*. Besides these, species of *Terebratula* and *Rhynchonella* are abundant.

Among Echinoderms *Cidaris*, *Hemicidaris*, *Mesodiadema*, and *Tiarechinus* make their appearance, and the last is restricted to the Trias. Of Crinoids *Dadocrinus*, *Isocrinus*, and *Encrinus* are found.

Corals (Anthozoa) also occur, especially in the limestones of the Upper Trias, and belong chiefly to *Cladophyllia*, *Calamophyllia*, *Thecosmilia*, *Isastrea*, and *Thamnastrea*.

Calcareous algæ, however, are the chief limestone builders, and have been described under the names of *Diplopora* and *Gyroporella*.

2. Lacustrine and Terrestrial Fauna

This is found in the Bunter and Keuper Series of England, Germany, and France, the animals being those which lived in or near the large inland salt lakes and lagoons, the plants those which grew on their borders and by the rivers which ran into them.

Plantæ.—The ferns are represented by the following genera: *Anomopteris*, *Chelipteris*, *Chladophlebis*, *Lacopteris*, *Coniopteris*, *Neuropteridium*, and *Tæniopteris*. The Cycads *Zamites*, *Otozamites*, and *Pterophyllum* are common plants. Conifers are represented by *Voltzia*, *Albertia*, *Baiera*, and *Schizolepis*. The horse-tail *Equisetites* also makes its appearance, as well as a new genus *Schizoneura*.

Mollusca.—Shells of this class are very rare, but a few resembling *Unio* and *Anodon* have been found, and others in the English Keuper which resemble *Thracia*, *Goniomya*, and *Pholadomya*.

Crustacea.—This class is represented only by the Phyllopod *Estheria*, which is abundant in the Keuper.

Pisces.—Remains of many kinds of fish occur, especially in the Keuper Beds, the more important genera being *Acrodus*,

Hybodus, *Ceratodus*, *Dipteronotus*, *Gyrolepis*, *Semionotus*, and

Fig. 112.—GROUP OF FOSSILS FROM THE ALPINE TRIAS.

1. <i>Pseudomonotis</i> Claral.	10. <i>Myophoria</i> Kefersteini.
2. <i>Naticella</i> costata.	11. <i>Cidaris</i> dorsata (spine).
3. <i>Tetractinella</i> trigonella.	12. <i>Chemnitzia</i> gradata.
5. <i>Ptychites</i> Studeri.	14. <i>Arcestes</i> tornatus.
6. <i>Ceratites</i> cassianus.	15. <i>Pinacoceras</i> Metternichi.
7. <i>Trachyceras</i> aon.	16. <i>Tropites</i> subbullatus.
8. <i>Halobia</i> rugosa.	22. <i>Monotis</i> salinaria.
	23. <i>Dadocrinus</i> gracilis.

Saurichthys. The ridged teeth of *Ceratodus* are abundant in some

parts of the German Trias, and closely resemble those of the living species of that genus.

Amphibia are still represented by Labyrinthodonts, the chief genera being *Labyrinthodon*, *Mastodonsaurus*, and *Trematosaurus*, but this order does not survive the Triassic period. Their tracks are five-toed, like the rough impress of a man's hand.

Reptilia.—Remains of true reptiles also occur, and include no

Fig. 113.—GROUP OF GERMAN MUSCHELKALK FOSSILS.

a. <i>Encrinurus lilliformis</i> .	d. <i>Myophoria vulgaris</i> .
b. <i>Terebratula</i> (<i>Cœnothyris</i>) <i>vulgaris</i> .	e. <i>Temnocheilus bidorsatus</i> .
c. <i>Gervillia</i> (<i>Hoernesia</i>) <i>socialis</i> .	f. <i>Ceratites nodosus</i> .

fewer than seven orders, several of which attained their maximum development in the succeeding Jurassic period. The Sauropterygia are represented by *Nothosaurus*, the Ichthyosauria by *Mixosaurus*, and the crocodiles by *Stagonolepis*, *Erpetosuchus*, *Ornithosuchus*, and *Belodon*. Dinosaurs occur for the first time in the forms known as *Paleosaurus*, *Zanclodon* (= *Teratosaurus*), *Thecodontosaurus*, and *Cladyodon*. Most of these creatures appear to have walked on their hind feet, after the fashion of a kangaroo; and as some of them

had only three toes, their footprints greatly resemble those of gigantic three-toed birds, and were supposed for a long time to have been made by such birds; other genera had four or five toes.

Still more characteristic of the Trias are reptiles belonging to the divisions known as Placodontia, Rhynchocephalia, Dicynodontia, and Theriodontia. The genus *Placodus* is found in Germany.

Fig. 114.—TRIASSIC VERTEBRATA.

a, b, c. Footprints, skull, and tooth of *Mastodonsaurus*.
d. *Dipteronotus cyphus*.

The Rhynchocephalia are represented by *Hyperodapedon* (which is allied to the modern *Sphenodon* of New Zealand), *Telerpeton*, *Leptopleuron*, and *Rhynchosaurus*. The Dicynodonts made their appearance in Permian time (see pp. 327 and 348), but the typical genus *Dicynodon* was first found in the Lower Trias of South Africa; it has not yet been found in the Trias of Europe.

The following are some of the more characteristic fossils of the German and English Trias :—

Fossils of the Bunter

<i>Plants.</i>	Schizoneura paradoxa, Voltzia heterophylla, Albertia elliptica, Æthophyllum speciosum.
<i>Mollusca.</i>	(In Germany only) Myophoria costata, Gervillia Murchisoni, Pleuromya mactroides, Beneckeia tenuis.
<i>Amphibia.</i>	Bones of Trematosaurus and Labyrinthodont footprints.

Fossils of the Muschelkalk

<i>Echinoderma.</i>	Encrinus liliiformis.
<i>Brachiopoda.</i>	Terebratula (Cœnothyris) vulgaris, Plicigera trigonella, Rhynchonella decurtata.
<i>Lamellibranchia.</i>	Myophoria vulgaris, Gervillia (Hœrnesia) socialis, Pecten discites, Lima striata, Trigonodus Sandbergeri.
<i>Gastropoda.</i>	Cœlostylina gregaria, Undularia scalata, Dentalium torquatum.
<i>Cephalopoda.</i>	Temnocheilus bidorsatum, Ceratites nodosus, Beneckeia Buchi.
<i>Pisces.</i>	Ceratodus Kaupi, Hybodus major, Acrodus Gaillardoti.
<i>Reptilia.</i>	Placodus gigas, Nothosaurus mirabilis.

Fossils of the Keuper

<i>Plants.</i>	Equisetites arcaceus, Pterophyllum Jægeri, Voltzia heterophylla, Schizoneura paradoxa, Danæopsis marantacea, Yuccites vogesiacus.
<i>Crustacea.</i>	Estheria minuta.
<i>Mollusca.</i>	Myophoria Goldfussi, Anoplophora donacina (German).
<i>Pisces.</i>	Acrodus minimus, Dipteronotus cyphus, Hybodus Keuperi, Palæoniscus superstes, Semionotus Bergeri.
<i>Amphibia.</i>	Mastodonsaurus giganteus.
<i>Reptilia.</i>	Hyperodapedon Gordoni, Telerpeton elginense.
<i>Mammalia.</i>	Tritylodon Fraasi (German).

C. THE TRIAS IN BRITAIN

The general extent of the Triassic deposits in England can be seen from any good geological map, and I assume that the student possesses the smaller Index Map of the Geological Survey.

With respect to the relations between the Trias and the Permian, recent observations have tended to show that the break between them is not of such magnitude as was formerly supposed. The outcrop of the Bunter follows the strike of the underlying Permian more or less conformably, especially in Devonshire, and, again, in the north-east of England; but there is unquestionably a break between them, accompanied by overstep which is unconformity. Some physical changes took place at the close of the Permian period, but the actual lapse of time between the cessation of Permian conditions and the formation of the Bunter Basement Beds may not have been great.

In order to avoid the repetition of detail, and to impart a

clearer idea of the component strata, it will be best to deal separately with each of the two great divisions of the Trias, for only two exist in Britain, the Bunter and the Keuper.

THE BUNTER SERIES

This set of beds has a more restricted range than the Keuper Series, a fact which is not always realised because it is concealed on a geological map by the overlap of the Keuper and the continuous outcrop of the latter all across England from south-west to north-east. The Bunter is not similarly continuous, but was deposited in two separate basins, a northern and a southern. The northern was much the larger of the two, extending from Worcestershire through the Midland counties, and including a large part of Northern England with probably a branch or gulf which reached into the north-east of Ireland and the south-west of Scotland. The southern basin was on the site of the pre-existent Permian lake, covering parts of Devon, Somerset, and the area of the English Channel.

The typical district of the British Trias is that of the Western Midlands, an area embracing Cheshire, South Lancashire, Shropshire, Staffordshire, and Worcestershire. Here the Bunter Series is divisible into three stages as below :—

The Upper Mottled Sandstone,	from 200 to 600 feet.
The Pebble Beds,	„ 300 „ 1000 feet.
The Lower Mottled Sandstone,	„ 200 „ 600 feet.

In describing these Bunter deposits it will be convenient to begin with this typical district, next to trace their extension to the north and north-east, and, finally, to notice their equivalents in the south of England.

1. *Central Area*

The Lower Mottled Sandstone.—In Cheshire and Shropshire this is usually variegated in bright red and yellow colours. It generally has a basal breccia about 2 feet thick lying unconformably on the Permian or the Coal-measures, but is otherwise devoid of pebbles. It always exhibits much oblique bedding, which has the aspect of current bedding, but is not a proof of deposition in water, for the sands may have been æolian, and the bedding be due to the action of wind, for in some of the beds the component quartz grains have the worn face and elongate oval shape which is characteristic of modern desert sands, the grains resembling millet-seed.

This Lower sandstone attains its greatest thickness (650 feet) near Bridgenorth, but is still about 400 feet near Chester. It

Fig. 115.—SECTION ACROSS THE TRIASSIC SERIES OF SHROPSHIRE (Ramsay).

ranges northward to the Mersey and then eastward along the southern border of the Lancashire coalfield, but thins in that direction, and does not occur at Manchester or Stockport. Moreover, it appears to thin out in every other direction, for, though it is found in places on the west side of the South Staffordshire coalfield, it does not appear on the east side. Southward, again, it extends to Stourport, and is probably continued underground as far as Worcester, but is overlapped in every direction by the succeeding Pebble Beds.

Clearly, therefore, this sandstone was accumulated within a restricted area, which was probably a desert plain, bounded on the west, south-east, and east by higher ground, but possibly reaching for some distance to the north-west below the Irish Sea.

The Pebble Beds.—These beds are most fully developed in East Shropshire and South Staffordshire. They pass eastward beyond the outcrop of the Lower sandstones, resting unconformably sometimes on the Permian, sometimes on the Coal-measures, as in Cannock Chase (see Fig. 116). In this central area they form a mass of conglomerate which is from 300 to 400 feet thick, and consists of well-rounded pebbles, the majority of these being brown and chocolate-coloured quartzites, with which, however, are pebbles of Carboniferous limestone and sandstone, of purple grit, and of some volcanic rocks. At the surface the sandy matrix is generally soft, but when traversed in deep borings it is very hard and highly calcareous.

Near Bridgenorth it has a breccia of angular fragments at its base about 60 feet thick, but this does not seem to extend far. It recurs, however, at Holt, on the river Dee, where it is succeeded by soft red-streaked sandstone overlain by pebbly sandstone, the whole series resembling that at Bridgenorth. Near Liverpool and St. Helens they attain a great thickness,

consisting of two parts, (1) hard, red-brown, pebbly sandstones, about 600 feet thick, and (2) hard, reddish sandstones without pebbles, about 400 feet. Eastward, by Wigan, Manchester, and Stockport, they overlap the Lower Mottled sandstones, so as to rest on the Dyassic and Carboniferous rocks.

On the east side of the South Staffordshire coalfield the Pebble Beds occupy a broad strip of country from Birmingham to the river Tame north-west of Tamworth, and they recur in a narrow strip along the western side of the Ashby coalfield in Leicestershire. In the same way from the borders of North Staffordshire coalfield, they pass eastward to Ashbourn and Derby, lying with complete unconformity on the edges of the Lower Carboniferous rocks.

The Upper Mottled Sandstone.—This resembles the Lower sandstone, but is generally of a bright red, variegated with yellow and white. From Shropshire, north of Shrewsbury, its outcrop runs northward by Ellesmere along the flanks of the Peckforton Hills, which rise to heights of 800 and 900 feet, and thence through Delamere Forest to Runcorn and Warrington on the Mersey. In the Peckforton Hills the outcrop is repeated by several strike faults which have led to the formation of as many nearly parallel escarpments, the western slopes of which are occupied by this soft, reddish sandstone, while their summit ridges consist of the hard basement conglomerate of the Keuper.

In the southern part of the Midland area all the Bunter stages thin out toward the south-east, one overlapping the other, a fact which may be regarded as proof that the pre-Triassic floor sloped from the south-east to the north-west. The following table indicates this attenuation and overlap :—¹

	Shropshire.	West Side of South Stafford- shire Coalfield.	East Side of South Stafford- shire Coalfield.	North Warwick.
Upper sandstone .	500	300	100	Absent
Pebble Beds .	400	300	200	Absent
Lower sandstone .	650	0 to 100	Absent	Absent
	1550	700	300	Nil

2. North-Eastern and Northern Areas

Having described the typical development of the Bunter Series, it will suffice to indicate briefly their occurrence beyond the limits of this Midland area.

Fig. 116.—SECTION FROM BREWWOOD TO LICHFIELD ACROSS THE NORTH END OF THE SOUTH STAFFORDSHIRE COALFIELD (by Professors Lapworth and Watts). Distance about 16 miles.

Fig. 117.—SECTION ALONG THE COAST OF DEVON, FROM RUDLEIGH TO SIDMOUTH (A. T. Metcalfe). Distance about 5 miles.

- f.* Clay with flints.
- e.* Upper greensand.
- d.* Keuper marls.
- c.* Keuper sandstone.
- c''.* Bunter sandstones.
- b.* Pebble Beds (Bunter).
- a.* Red marls (? Permian).

Though overlapped by the Keuper marls in the valley of the Trent east and south-east of Derby, the Bunter is probably continuous as a narrow strip beneath them, since it recurs near Nottingham and extends northward for a considerable distance. The Upper Mottled sandstone, however, is absent throughout this eastern area. Near Nottingham the Lower sandstone has the usual bright-red and yellow tints, but is there only 25 to 30 feet thick; northward, it thickens to about 100 feet at Mansfield. As in the western area, it seems to occupy a tract of limited width, and to be overlapped eastward by the Pebble Beds, which are the lowest recognisable Triassic deposits in deep borings at South Searle near Newark, and at Haxey in North Lines.

The Pebble Beds form the rock on which Nottingham Castle stands, where they are about 200 feet thick, and consist of a coarse yellowish sandstone full of quartzite pebbles. They range northward through Sherwood Forest by Worksop, Tickhill, and Doncaster. Along this tract the thickness of the Bunter is about 450 feet, and in a boring near Selby it is 620 feet; but beyond this place the pebbles disappear, and the whole Bunter division is supposed to thin out near Knaresborough, though it may extend eastward underground beneath South Yorkshire.

There is a similar disappearance of the pebbles on the western side of the Pennine Anticline in North Lancashire, but the combined Bunter sandstones persist and are about 1000 feet thick near Preston and Garstang. They recur in the promontory of Furness on the western side of Morecambe Bay, and extend along the western side of Cumberland to St. Bees (see map, Fig. 39, p. 130), where they are known as the St. Bees' sandstone.

This St. Bees' sandstone is the sole representative of the Bunter in the Carlisle basin, and along the valley of the Eden, unless the underlying gypsiferous marls are included in the Trias (see p. 337). These latter vary in thickness from 100 to 300 feet, and pass up into the overlying sandstone by intercalations of sandstones and marls. The St. Bees' sandstone is sometimes variegated in the lower part, but most of it is of a dull, uniform, brick-red colour. It contains some bands of pebbly sandstone, and its thickness is estimated at over 1000 feet.²

A similar sandstone has been found by borings in the northern part of the Isle of Man³; and again in Ireland, near Belfast, where the Keuper is underlain by about 800 feet of soft red and yellow sandstones with some beds of grey and buff shale.

Rocks of Triassic age occur again in the Isle of Arran, occupying much of the central and southern part of that island. The lower portion of them is coloured as "Lower Trias" on the recent map

of the Geological Survey, though it was described as Permian in the "Summaries of Progress" for 1896 and 1898. These lower beds are about 1000 feet thick, and consist of bright-red sandstones with conspicuous current bedding, thus resembling the Penrith Beds rather than the St. Bees' sandstone. They are overlain and overlapped by conglomerates, which are probably of Triassic age, though they seem to follow in conformable succession.

3. *South-Western Area*

In this district there is nothing comparable with the Lower Mottled sandstone of the Midlands, and in the typical section of the south coast of Devon, near Budleigh Salterton, the Bunter is less than 500 feet thick. It is composed of the following beds:—

2. Coarse red sandstones . . . from 350 to 400 feet.
1. The Pebble Bed or conglomerate . about 80 feet.

The Pebble Bed rests directly on the red Permian marls mentioned on p. 333, but without any sign of erosion, for the lowest pebbles are embedded in a sandy clay which is continuous with the marl below. The mass of the Pebble Bed consists of well-rounded oval pebbles of quartzite and hard grit embedded in a matrix of red sand; it exhibits current bedding and includes lenticular layers of sand. Some of the pebbles contain Devonian fossils, and others are Silurian and Ordovician, resembling the Grès armoricain and the Grès du May of Brittany and the Ordovician rocks of Cornwall. Dark, compact, tourmaline rocks also occur, like some which occur in the metamorphosed zones round the granite masses of Devon and Cornwall.

According to Professor Bonney, however, the majority of the pebbles do not resemble Devon and Cornwall rocks, while there are some of a hard red quartz-felspar grit which resembles the Torridon sandstone of Scotland, but is equally like some parts of the Grès felspathique at the base of the Ordovician in Normandy. It is, in fact, now generally conceded that this assemblage of pebbles was brought by a river or rivers from the south, *i.e.* from Normandy and from land which then occupied the southern part of the English Channel. Oval quartzite and quartz-grit pebbles have, in fact, been dredged from the floor of the Channel at many points from 15 to 50 miles south of the Eddystone.

This conglomerate can be traced inland through Devonshire into Somerset, but the pebbles become smaller in that direction, and the quartzites becomes less and less abundant, till at Burlescombe the bed passes into a sandy gravel composed chiefly of small quartz and grit pebbles.⁴

The overlying sandstones are coarse, current-bedded, red sandstones, and in the lower 100 feet they contain a few pebbles of quartz and quartzite, with occasionally subangular fragments of granite, felspathic grit, and lumps of hard red marl. The higher beds are less coarse and more massive, and from these bones of *Hyperodapedon* have been obtained. These beds occupy the coast from the mouth of the Otter to Sidmouth (see Fig. 117).

THE KEUPER SERIES

This series has a much wider extension than the Bunter, and its higher beds were formed in a great salt lake which covered both the Bunter areas of deposition as well as all the intermediate parts of Central England. Borings at several places in the Midland and Eastern counties have proved that the Keuper sandstones and marls extend eastward beneath the Lias and newer rocks till they thin out against the western slope of the great mass of Palæozoic rocks which underlies the south-east of England.

Thus, a boring at Burford in Oxfordshire passed through 428 feet of Keuper Beds, and entered Coal-measures at 1184 feet from the surface. Borings near Northampton found only 60 to 70 feet of Trias above the older rocks, and one at Culford near Bury St. Edmunds proved its absence. It is also absent below Richmond and London, but appears to pass under the Wealden area as beds underlying Lias, and believed to be of Keuper age, were traversed by a boring at Brabourne in Kent.

As in dealing with the Bunter, we shall first describe the complete and typical development of the Keuper Series in the Midland area, and then indicate such stratigraphical variations as occur when it is traced eastward, northward, and southward.

1. *Typical Midland Area*

In this area the Keuper Series is divisible into three very unequal parts:—

	Feet.
Red marls with rock-salt	from 1000 to 3000
“Waterstones,” flaggy sandstones and shales	about 200
Basement beds, sandstone, and breccia	from 100 to 250

Lower Sandstone or Basement Beds.—The actual base of the series is generally a bed of calcareous breccia, but sometimes a hard pebbly quartz grit; this rests on an eroded surface of the Bunter sandstone (see p. 357), and marks a sudden change in the physical conditions, though the break does not amount to an

unconformity, for there is no proof that this basement bed rests on different parts of the Bunter Series in different places.

The overlying sandstones are rather coarse grained and irregularly bedded, generally of bright colours, red or yellow, but sometimes pink or white. The current bedding is remarkable, and the laminae often dip at high angles and change within short distances.⁵ The thickness is variable, but often about 200 feet, and the group is persistent throughout Cheshire, Shropshire, Staffordshire, and Worcestershire. To the south-east, however, it thins out, and is absent in Warwick.

Fossils have recently been found in the upper part of these beds at Bromsgrove in Worcester⁶; they include both plants and animals. The plants have been identified by Mr. Arber as *Equisetites arenaceus*, *Yuccites vosgesiana*, and *Voltzia heterophylla* (twigs and cones). The animals are *Hyperodapedon Gordoni*, a Labyrinthodont (? *Mastodonsaurus*); the fish, *Dipteronotus* and *Acrodus*, *Estheria minuta*, and fragments of Arthropods which are probably scorpions.

The **Waterstones** are brownish, even-bedded micaceous sandstones and flagstones, with layers of red or green sandy shale; they are therefore very different from the underlying beds upon which they rest with a sharp line of demarcation.⁷ Their surfaces exhibit ripple-marks, sun-cracks, and they contain casts of salt-crystals, all clear indications that they were deposited in shallow water. Their average thickness is about 200 feet, but there is no definite summit to the group as it passes up by intercalations of shale and marl into the overlying Keuper marls.

When traced south-east into Warwickshire, they overlap the Lower sandstones and rest directly on the Carboniferous rocks. In some places the waterstones have yielded bones and teeth of *Labyrinthodon*, *Cladyodon*, and *Hyperodapedon*, and also teeth of the fish *Dipteronotus cyphus*, but these remains are rare. Reptilian and Labyrinthodont footprints, however, are not uncommon.

The **Keuper Marls**, though the thickest and most important members of the series, are in some respects the least interesting, because they consist of a monotonous succession of red clays (or "marls") varied only by nodular layers and beds of gypsum and occasionally beds of rock-salt, which are sometimes from 70 to 100 feet thick.

The thickness of these saliferous marls in Cheshire is from 2000 to 3000 feet; in Shropshire it is from 1500 to 1800, thinning eastward to 800 and 700 in Staffordshire, and about 600 in Warwickshire and Leicestershire. In the last county they overlap the sandstones and are banked against the Archæan rocks of Charnwood Forest, partially filling the valleys between the hills.

In the Worcester, Warwick, and Leicester areas a bed of grey sandstone, about 20 to 30 feet thick, occurs near the top of the series and is known as the Shrewley sandstone, from Shrewley between Birmingham and Warwick, where it is well exposed. It has yielded remains of fish (*Palæoniscus superstes*), with *Estheria minuta* and some casts of bivalve Mollusca, which, according to Mr. E. F. Newton, resemble *Goniomya*, *Pholadomya*, and *Thracia*.

2. North-Eastern Area

Basement Beds.—Near Nottingham these are represented by an irregular deposit of white sand, which rests on an eroded surface of the Bunter Pebble Beds and varies from a few inches to many feet in thickness. Mr. J. Shipman has described certain pebbly sandstones more than 100 feet thick, which he regards as representing this deposit.⁸

The Waterstones which succeed generally have a pebbly or conglomeratic bed at the base, and this rests sometimes on the white sand deposit, and sometimes directly on the Bunter, but always on an eroded surface, so that it seems to be unconformable to the beds below. The pebbles are chiefly quartz and quartzite, but Mr. Shipman has detected fragments of trap, slate, chert, and magnesian limestone. The waterstones themselves consist of soft brown sandstones interstratified with red marls, which cause plentiful springs by throwing out the water collected in the sandstones. Ripple-marks and sun-cracks are frequent in these beds.

The Keuper Marls.—These are considered to begin when the marl bands become thicker and the interbedded sandstones become harder and generally white or bluish-grey. Of such beds there is about 150 feet. Gypsum occurs in the marls, and the higher beds are chiefly marl with sheets and nodules of gypsum. The whole is about 900 feet thick (see Fig. 118).

In Yorkshire the Keuper appears to become thinner and not to exceed 700 feet in thickness; it is still capable of division into an upper red marl group, about 400 feet thick, and a lower series of red and white sandstones from 200 to 300 feet thick, but its lower limit is somewhat uncertain in the northern part of the county.

3. Cumberland and Irish Sea Area

Beds of Keuper age overlie the St. Bees' sandstone in the Carlisle basin, and so far resemble the Midland type that they consist of a lower sandstone division and an upper gypsiferous marl group. The former is known as the Kirklington sandstone

and is about 500 feet thick ; the latter (Red Marls) are estimated at 950 feet.

The Kirklington sandstone is only seen in the eastern part of the basin, its outcrop elsewhere being concealed by the Drift deposits. It consists of soft sandstones, which are in some parts red, in others white, or sometimes mottled red and white, and they are probably the equivalents of the Cheshire "waterstones."

The Keuper marls are also for the most part buried beneath Drift, but near Carlisle the sandstones are covered by red and grey marls, which are exposed in several places on the banks of the Eden. West of Carlisle there is believed to be a fault of considerable magnitude, for borings have shown that a great thickness of red shaly marls with gypsum and rock-salt is brought into the western and deeper part of the basin.⁹

Keuper marls also occur beneath the northern part of the Isle of Man, borings having proved a thickness of 557 feet with 21 beds of rock-salt, one of these being 16 feet thick. Below are 800 feet of sandstone, part of which is probably also of Keuper age.

In Ireland the largest area of Trias occurs in the valley of the Lagan, and extends from Lurgan to Belfast, and thence along the northern shore of Belfast Lough as far as Black Head. The beds are also seen at intervals along the coast to the northward as far as Red Bay near Cushendall. They are thickest in the southern part of the area near Belfast. Rock-salt is found at Carrickfergus, where the general succession is as follows :—

	Feet.
Keuper { Red marls with gypsum	700
{ Rock-salt and blue clays	150
{ Brownish sandstones	perhaps 20
Bunter { Soft red and yellow sandstones with grey	
{ and buff shales	800

Writing of the Trias in the Isle of Man, Professor Boyd Dawkins remarks that "the unexpected presence of the Saliferous Marls is a link uniting the Triassic strata of the north of the island with those of Barrow on the one hand, and Carrickfergus on the other. It is very probable that these three salt-fields belong to one great saliferous basin underlying the Irish Sea, extending southward and eastward to join that of Fleetwood [in Lancashire], and to the south in the direction of the great salt-field of Cheshire."¹⁰

4. Mendip and Bristol Channel Area

It is convenient to deal separately with this area because its connections with the areas to the north and south are narrow, and because it exhibits a somewhat peculiar local facies of the Keuper.

As stated on p. 359, this area was land during the formation of the Bunter Beds, and it was not covered by the waters of the Keuper lake until a late epoch in the period; indeed, the Mendip Hills were never completely covered by these waters, and the flanks of these hills display an interesting arrangement of littoral deposits.

These deposits consist of breccias and conglomerates with a calcareous matrix, and are known as the "Dolomitic Conglomerate." They are mainly composed of pebbles of Carboniferous limestone,

Fig. 120.—GEOLOGICAL MAP OF BACKWELL HILL BETWEEN BRISTOL AND WRINGTON.
(Surveyed and drawn by Professor S. H. Reynolds.) Scale $1\frac{1}{2}$ inch to a mile.

d. Lias.
c. Keuper.

b. Dolomitic conglomerate.
a. Carboniferous limestone.

most of these being about the size of a hen's egg, but ranging up to boulders of 2 or 3 feet in diameter, the whole being compacted by a calcareous cement which is generally dolomitic. These beds dovetail into calcareous sandstones and red marls (see Fig. 121), the latter of which fill the wider spaces between the islands of older rocks. Remains of *Palæosaurus* and *Thecodontosaurus* have been found in the conglomerate deposits.

The manner in which the conglomerates run up into the limestone hills along the lines of the old valleys is illustrated in Fig. 120, and, from the contours indicated on this map, it will be seen that these old inlets have no relation to the modern valleys.¹¹

A continuation of these beds is found in South Wales, where they occur in patches from Cardiff westward as far as Porth Cawl and Kenfig, with a small outlier in Gower which indicates a still further extension to the west. The beds surround islands of Old Red Sandstone and Carboniferous limestone, and their thickness, of course, varies, but there is generally a border or base of dolomitic breccia which passes up into red marls with layers of red and white limestone; these are succeeded by red clays, and, finally, by green clays or marls.¹²

On the Somerset side of the Channel a similar set of red breccias, sandstones, and marls is found all round the Quantock Hills, and along the coast from Watchet to Porlock, where they occupy an ancient strait between the Brendon Hills and that called North

Fig. 121.—SECTION TO SHOW THE RELATIONS OF THE TRIAS TO THE CARBONIFEROUS ROCKS NEAR SHEPTON MALLET (Somerset).

l. Lower Lias.	4. Millstone grit.
r. Rhaetic Beds.	3. Carb. limestone.
k. Keuper marls.	2. Carb. shale.
c. Conglomerate.	1. Old Red Sandstone.

Hill on the coast line. The Quantock Hills were an island in the great lake, and the Trias is bedded into a similar old valley or strait on the west of them.¹³

5. Devonshire

South of Taunton the thickness of the Keuper Series becomes greater, though the actual outcrop is narrowed by the overstep of the Cretaceous strata which form the Blackdown Hills. The whole series, however, is well exposed on the cliffs of the south coast, from Sidmouth to Seaton and Axmouth. Here the following succession of beds is found :—

			Feet.
Keuper	{ Red and green marls . . .	about	300
	{ Red marls with gypsum . . .	„	1000
	{ Red sandstones . . .	„	75

Keuper.—According to Professor Hull and the Rev. A. Irving,¹⁴ the base of the Keuper division should be taken at a bed of hard breccia about two feet thick which can be seen below the footbridge

over the Sid at Sidmouth. Above this are pale-red and grey sandstones with seams of marl, succeeded by alternating bands of sandstone and marl, the beds in which sandstones predominate being about 75 feet thick.

The succeeding beds are red marls with thin sandstones in the lower 150 feet, but passing up into massive marls with a conchoidal fracture containing strings of gypsum and pseudomorphs of rock-salt. These form the lower part of the cliffs as far as Branscombe mouth, but near Beer Head a syncline carries them below the beach. Higher beds occur in the Axmouth and Bindon cliffs, where they finally pass up into the Rhætic Beds.

6. *Scotland*

Rocks of Triassic age occur in several parts of Scotland, but, though they resemble the English Trias in consisting largely of red sandstones and marls, their stratigraphical arrangement is different, and this area has therefore been left till the last. The possibility that the Bunter is represented in Arran has been mentioned on p. 361, but in the more northern districts it is probable that all the beds are of Keuper age.

Arran.—The beds described on p. 361 are succeeded by red sandstones, and these are overlain by red shales and marls. Moreover, recent exploration of the agglomerates which fill up the vent of a huge Tertiary volcano in the central part of the island has led to the discovery of large masses of rock which show a sequence from red marl through Rhætic shales into Lower Lias, thus proving the red marls to be of Keuper age, and to have been succeeded by Rhætic and Liassic Beds, though all other traces of these beds have been destroyed by erosive agencies during Tertiary times.¹⁵

Western Coast.—Small patches of Trias occur at the base of the Neozoic rocks in Morvern and Ardnamurchan (Argyleshire), in the Isles of Skye and Raasay, and on the coast of Gruinard Bay in Ross-shire. They have been described by Professor Judd, who remarks that the materials forming the breccias, conglomerates, and coarser sandstones have evidently been derived from the older rocks on which these strata repose, usually either the Torridon sandstone or some member of the Highland gneissic series.

A special feature in these Triassic rocks is the abundance of calcareous matter which enters into their composition; fragments of compact limestone (? Durness limestone) abound in the coarser beds; the sandstones often pass into calcareous grits, and bands of cornstone are not unfrequent, while all the beds are frequently traversed by veins of calcspar. As a rule, breccias and

conglomerates prevail in the lower part of the series, sandstones, marls, and limestones in the upper part, but the succession of beds is very irregular and inconstant. At Gruinard Bay the total thickness exceeds 1000 feet; at Raasay it is probably less than 500 feet, though the general succession is the same; at Lussay, in Skye, it is reduced to a few feet, and southward, in parts of Mull and Morvern, it varies from 50 to 500 or 600 feet.

The following is the succession at Gruinard Bay :—

	Feet.
Soft reddish argillaceous and sandy beds with bands of hard white and greenish sandstone	200
Red and variegated marls with thin beds of sandstone and concretionary limestone	200
Red argillaceous sandstones and conglomerates, alternating in the lower part with masses of coarse breccia-conglomerate	500

Eastern Coast.—Small tracts of Trias occur in Elgin and on the coast of Sutherland. The tract in Elgin extends from Spynie, north of Elgin, to the coast at Lossiemouth and Stotfield Head.¹⁶ It rests on the O.R.S., but its base is not exposed. The rock seen in quarries is a white sandstone, massive, fine-grained, and fairly soft, with a thickness of about 200 feet, apparently dipping north, and overlain at Stotfield by a hard, whitish, cherty limestone, which may be 30 feet thick. This sandstone has yielded remains of eight different reptiles: three Rhynchocephalians, *Hyperodapedon*, *Telerpeton*, and *Stenomelanos*; two Crocodiles, *Stagnolepis* and *Erpetosuchus*; and two Thecodonts, *Ornithosuchus* and *Scleromochlus*.

The same two kinds of rock occur below Dunrobin Castle on the Sutherland coast, *i.e.* white sandstone dipping north-east, and passing below a cherty rock like that of Stotfield, above which are beds of Liassic age.

D. THE TRIAS IN EUROPE

1. Germany

Triassic rocks occupy large areas in Central and Southern Germany, in Thuringia, Hesse, North Bavaria, Württemberg, and Lorraine; they are also found in the Eifel district, in Hanover, Brunswick, and Magdeburg, and finally in the island of Heligoland. From the Rhine district they extend westward to Luxemburg, and through the Vosges Mountains into France. They are everywhere divisible into the three series of Bunter, Muschelkalk, and Keuper.

The German Trias was formed under the same physical and geographical conditions as that of Britain, with which it is prob-

ably continuous under the bed of the North Sea; in other words, the British area was part of a much larger Germanic region. The German Bunter and Keuper may both be regarded as salt-lake or lagoon deposits, and though the fossils of the Muschelkalk are marine, yet its fauna is not a large one, and is evidently that of an inland sea which was only temporarily connected with the open sea to the south. The area over which these limestones occur may be regarded as including what was the deepest part of the great depression occupied by this inland sea.

The subdivisions of the German Trias and their average thicknesses are given in the following table:—

	Feet.
Keuper { "Steinmergel," marls without gypsum	300 to 500
Keuper { Gypsiferous red and green marls	500 to 700
Keuper { Kohlenkeuper	200
Muschelkalk in three stages	600 to 1000
Bunter { Upper Bunter marls	300
Bunter { Middle Bunter sandstones	700 to 1000
Bunter { Lower shaly sandstones	300 to 500
	<hr/> 3000 to 4000

The Bunter.—This is essentially a sandstone series. The lower stage in Northern and Central Germany consists of dark-red flaggy sandstones, which succeed with apparent conformity the clays of the Upper Zechstein, but in Western Germany they overstep the whole of the Permian, and rest on the crystalline schists of the Odenwald and the Black Forest. The rest of the Lower Bunter consists of fine-grained micaceous sandstones of various colours, often speckled, and often including angular fragments of red clay; there are also some layers of dolomitic sandstone (*Rogenstein*). (See Fig. 122.) Fossils are rare.

The main mass of the Bunter sandstone (or Middle Bunter) consists of coarse quartzose sandstones, which generally show current bedding and have a maximum thickness of 1000 feet. No fossils except tracks of Labyrinthodonts have been found.

The Upper Bunter or R $\ddot{o}$ th consists of variegated red and green marls with beds of gypsum and rock-salt. In Thuringia these beds contain layers of dolomitic limestone with marine fossils (*Myophoria costata*, *M. vulgaris*, and other species which also occur in the Muschelkalk). Westward in the Eifel, the Vosges, and Lorraine the R $\ddot{o}$ th passes into fine argillaceous sandstones containing plant remains, *Voltzia*, *Schizoneura*, and *Anomopteris*.

Muschelkalk.—This is a limestone series, and takes its name from the abundance of bivalve shells ("muscheln") in many of its beds. It is divisible into three stages.

The lower stage is about 300 feet thick, and consists of thin-bedded marly limestones (Wellenkalk) with yellowish porous limestones (Schaumkalk). The chief fossils in the lowest beds are *Myophoria orbicularis*, *Natica gregaria*, and *Dentalium torquatum*, but the higher part of the Wellenkalk is one of the richest fossiliferous zones in the whole series, its fossils including *Myophoria vulgaris*, *Gervillia costata*, *Pecten discites*, *Terebratula* (*Cænothyris*) *vulgaris*, *T. (Aulacothyris) angusta*, and *Beneckeia Buchi*.

The middle stage consists chiefly of dolomitic limestone and marl with beds of gypsum and rock-salt. Fossils are rare.

The upper beds are hard limestones, consisting mainly of Encrinite stems, overlain by thin-bedded limestone characterised by *Ceratites nodosus*. These upper beds are rich in fossils, some of the commonest being *Encrinus liliiformis*, *Lima striata*, *Gervillia* (*Hærniesia*) *socialis*, *Terebratula* (*Cænothyris*) *vulgaris*, *Myophoria vulgaris*, and *Temnocheilus bidorsatus*.

In the Vosges country some of the Muschelkalk limestones are replaced by sandstones and marls, and the whole division gradually dwindles till it finally thins out and disappears.

The Keuper.—The main area of the German Keuper lies in Franconia and Swabia (Württemberg), but it also occupies a considerable space in Luxemburg and in Alsace-Lorraine. It occurs also in the middle of the Thuringian basin and to the north-east of the Teutoburger Wald (in Hanover and Brunswick). The series is everywhere divisible into three groups, which have a combined thickness of from 900 to 1200 feet (see Fig. 122).

The *Kohlenkeuper* consists of dark-grey shales and sandstones with thin beds of shaly coal, but the fossils are marine and brackish water, some of the beds being crowded with *Estheria minuta* and *Lingula tenuissima*, with the teeth of fishes (*Ceratodus*, *Acrodus*, and *Hybodus*). The highest beds of the group are yellow dolomitic limestones—some compact, some oolitic—and these contain *Myophoria Goldfussi*, *M. transversa*, and *Anoplophora donacina*.

The central beds, forming the main mass of the Keuper, are red and green marls with beds of gypsum and some of rock-salt. Fossils are rare in these marls, but in South Germany (Stuttgart) they include plant-bearing sandstones with *Equisetites arenaceum* and *Pterophyllum Jægeri*.

The *Steinmergel* seems to correspond with the highest red and green marls of the English Series. They are free from gypsum and rock-salt, but contain thin layers of sandstone and, in Lorraine, beds of dolomite and layers of dolomitic concretions. From these beds many Reptilian remains have been obtained, e.g. *Aëtosaurus* and *Belodon*, and the Dinosaurs *Dimodosaurus* and *Zanclodon*.

2. *The Alpine Facies*

The Triassic System has no great thickness in the Western or Central Alps, but attains a great development in the well-known Dolomite Mountains of the South Tyrol and Carnic Alps, and also in the Vorarlberg, in North Tyrol, Salzburg, and Bavaria, on the northern side of the main crystalline axis of the Alpine chain. The succession of beds forming the lower and middle parts of the system in the northern districts differs considerably from that in the southern, but the higher part from the Raibl Beds upwards is similar in both regions. From this and from differences in the Cephalopodan faunas of the two areas it was inferred that there were at first two marine provinces which were more or less separated until the later part of the Triassic period. The northern province has been called the Juvavian, and the southern the Mediterranean province. The former includes Bavaria, the Salzburg district, and Austria proper, extending eastward to the Carpathians; the latter comprises the Lombardy Alps, the Southern Tyrol, Carinthia, with the whole of Italy and the whole Dalmatian and Bosnian region. The progress of research, however, has shown that the differences are less than were supposed, and that, so far as the fossils are concerned, it is rather a matter of relative abundance of species than of difference in fauna.

The thicknesses of the several divisions vary much in different districts, but the total thickness in the North Tyrol is supposed to be about 6000 feet, while in the South Tyrol it is probably about 9000 feet. The following table shows the general succession in the two regions:—

Southern Region.		Northern Region.	
8. Lower Dachstein Dolomite		Main Dolomite	} Keuper.
7. The Raibl Beds		Raibl or Cardita Beds	
6. The St. Cassian Beds		Partnach Beds	} Muschelkalk.
5. The Wengen Beds		Reiffling limestone	
4. The Buchenstein Beds }		Guttenstein limestone	
3, 2. The Virgloria limestone		Werfen Beds	Bunter.
1. The Werfen Beds			

The whole system has also been divided into zones and into stages or series of more equal palæontological value, but much difference of opinion still exists as to the number of zones and as to their grouping, and many names have been proposed for the different groups or stages. The following table gives the principal zones, which correspond to the local subdivisions as numbered above, and the names which seem most applicable to the

stages, the latter being almost the same as those proposed by Mojsissovics:—¹⁷

	Stages.	Zones.
Upper	E. Juvavian	8. <i>Avicula exilis</i> .
	D. Carinthian	7. <i>Trachyceras aonoides</i> .
	C. Norian	6. <i>Trachyceras aon</i> .
Lower		5. <i>Trachyceras archelaus</i> .
		4. <i>Trachyceras Curioni</i> .
	B. Dinarian	3. <i>Ceratites trinodosus</i> .
	A. Werfenian	2. <i>Ceratites binodosus</i> .
		1. <i>Tirolites cassianus</i> .

More recently he has proposed to combine the Norian and Carinthian into one stage or series, for which he adopts the name Tirolian, but the advantage of this is not very apparent.

The Werfenian, or zone of *Myophoria costata*, is fairly constant in its lithological and palæontological characters throughout the Alpine and Austrian region. Its prevalent facies is one of red sandy micaceous shales, but in the Carnian Alps there are intercalated beds of marly and dolomitic limestones, and in the Tyrol it also consists of shales and limestones which have been divided into two groups, the Seiss Beds and the Campil Beds. The Ammonoid *Tirolites cassianus* is found in both provinces, associated with *Myophoria costata*, *Naticella costata* (Fig. 112, No. 2), and *Pseudomonotis Clarae* (Fig. 112, No. 1). In the South Tyrol the thickness of this stage is only 300 to 500 feet.

Dinarian, or Alpine Muschelkalk.—It is at this stage that the differences between the southern and northern provinces become pronounced. In the Southern Alps it is represented by the Virgloria limestone and its equivalent, the Mendola Dolomite, and in the South Tyrol there is a lower set of bedded limestones overlain by Mendola Dolomite. In the more northern districts there are two groups or zones, the Guttenstein limestone or zone of *Ceratites binodosus* and the Reiffling limestone or zone of *C. trinodosus*. The Dinarian contains many of the same species as the German Wellenkalk, notably *Cænothyris vulgaris*, *Terebratula (Aulacothyris) angusta*, *Tetractinella trigonella* (Fig. 112, No. 3), *Gervillia (Hærnesia) socialis*, *Myophoria vulgaris*, and *Encrinurus liliiformis*. The thickness varies from 400 to 1200 feet.

The Norian.—In the southern province this comprises the Buchenstein shales, with calcareous nodules containing *Trachyceras Curioni*, and the Wengen Beds, which include black shales and calcareous grits containing *Trachyceras archelaus* and *Halobia Lommeli*, succeeded by thin-bedded limestones and shales with *Posidonomya wengensis*. In the Juvavian province these are replaced by the higher part of the Reiffling limestone and by the

Wetterstein limestones, so that there the stage is wholly calcareous. A large number of peculiar Ammonoids come in with this series, such as *Pinacoceras Metternichi*, *P. parma*, *Cladiscites tornatus*, *Arcestes ruber*, and species of *Diphyllites* and *Megaphyllites*. The thickness varies from 2000 to 3000 feet.

The Carinthian.—The separation of the two provinces appears to have continued through this group up to the phase of the Raibl Beds, when similar conditions began to prevail over the whole region. In the Mediterranean province the Wengen Beds are overlain by the St. Cassian Beds, a series of fossiliferous marls, shales, and limestones with occasional beds of volcanic tuff. Among the large number of fossils which these beds afford the following may be mentioned: *Trachyceras aon* (Fig. 112), *Choristoceras eryx*, *Orthoceras elegans*, *Naticopsis neritacea*, *Halobia cassianus*, *Anoplophora Munsteri*, *Cidaris dorsata*, *Encrinurus cassianus*, *Isocrinus propinquus*, *Thamnastrea Zitteli*, *Koninchina Leonhardi*. The St. Cassian Beds are succeeded by the Raibl Beds, dark-grey marls with lenticular beds of limestone and some of gypsum, the chief fossil being *Myophoria Kefersteini* (Fig. 112, No. 10).

In the St. Cassian area of the Tyrol a mass of dolomitic limestone, the Schlern Dolomite, from 1000 to 1400 feet thick, comes in between the St. Cassian and the Raibl Beds,¹⁸ and this thickens southward, replacing more and more of the beds below and above till in the Schlern and Rosengarten districts it rests directly on the Mendola Dolomite of the Norian stage, and is then about 3000 feet thick with a small equivalent of the Raibl strata at the top. Consequently it then represents both the Norian and Carinthian (see Fig. 123).

In the North Tyrol and Bavaria the St. Cassian Beds are represented by the Partnach Beds with the overlying Raibl Beds, but in the Austrian Alps to the eastward there is a different succession, consisting of (1) the Rangraben shales, (2) the Linz sandstone with plant remains, (3) the Opponitz limestone.

Juvavian.—Finally, over the whole region we have the massive dolomitic limestones known in Austria as the Hallstadt and Dachstein limestones and in Lombardy as the Great or Main Dolomite. These masses of limestone are several thousand feet thick, but fossils are rare in them, except casts of the large bivalve *Megalodon*; *Gervillia exilis* and *Worthenia solitaria*, though less common, are characteristic species. These limestones pass up into the Kössen or Rhætic limestones and are by some authors regarded as Lower Rhætic, but it is only the Upper Rhætic or zone of *Avicula costata* which overlies the Keuper of Germany, France, and England. Hence it is almost certain that the zone

of *A. exilis* was contemporaneous with the highest part of the Keuper.

The probable correlation of the several series of beds in England, Germany, and the Tyrol is shown in the following table :—

BRITAIN	GERMANY	THE TYROL
KEUPER	KEUPER	JUVAVIAN
	MUSCHELKALK	
BUNTER	BUNTER	CARINTHIAN
	PERMIAN	NORIAN
PERMIAN		DINARIAN
		WERFEMAN

Vertical Scale 6000 feet to an inch.

3. France

The surface areas occupied by Trias in France are small, though the Keuper probably has a considerable subterranean extension both in the northern and southern parts of the country:

From the Vosges district and the Sarrebruck area in Alsace a broad tract of Trias reaches westward into France, passing under the Jurassic strata which occupy the great basin between the plateau of the Ardennes and that of the Morvan. All the members of the German Trias are here present, but both the Bunter and the Muschelkalk thin rapidly to the westward; their attenuation can be followed along the northern outcrop in Luxemburg, and both are very thin before they are overlapped by the Lias north-west of Arlon.

There can be no doubt that a similar thinning out takes place to the south-west of the Vosges, for when the beds emerge on the borders of the Morvan only Keuper remains, but this is exposed at intervals round the Morvan and along the north side of the Central Plateau from the valley of the Allier to a point about 15 miles west of La Châtre. Though the beds are of no great thickness, they seem to represent the Lower or Kohlenkeuper as well as the higher marls. They can be traced southward along the eastern border of the Plateau to Macon, Villefranche, and Lyons, the beds consisting of coarse quartzose and felspathic sandstones from 50 to 100 feet thick, surmounted by a pink dolomitic limestone with *Myophoria Goldfussi*, which is succeeded by Keuper marls.

At Lyons the sandstone rests directly on the ridge of Archæan

rocks which here crosses the valley of the Rhone between that place and Valence, and it is probable that this was part of the barrier which separated the northern and southern basins of depositions. South of Valence similar deposits set in again and form a long strip by Privas and Largentière, and again in the Lodève district; they also occur in the Pyrenees and in Eastern Spain, but to find a complete Triassic Series one must go to the Maritime Alps, where lower beds come in and the series expands eastward into the Apennine facies which is similar to that of the Eastern Alps.

The only other Triassic tract in France which need be noticed is that in Normandy, occupying a bay-like depression in the Archæan rocks from Valogne and St. Waast on the north to St. Lo and Littry on the south, but thinning out to the west of Caen. The beds consist of gravel and conglomerate at the base, passing up into a dolomitic conglomerate which is succeeded by red sandstones and marls. The maximum thickness is not more than 200 feet, and the whole is probably of Keuper age, the beds being shore deposits, like those round the Mendip and Quantock Hills in England.

E. THE HISTORY OF THE EUROPEAN TRIAS

From the preceding descriptions of the Triassic strata which are found in different parts of Europe the student will have gathered that considerable geographic changes took place during the course of the period; though these seem to have been accomplished slowly and without the forcible uplift of any mountain chain like that of the Armorican ranges in Carboniferous time.

The change from Permian to Triassic conditions seems to have been effected by a slow upheaval of the whole of Northern Europe, so that all those parts of the Permian Sea which lay within that region were shallowed and some portions of them were converted into sandy plains. This seems especially to have been the case in the British area where the north-west gulf of the Permian Sea became a sandy desert, swept by winds which probably blew chiefly from the north, like those which blow over Persia and Beluchistan at the present day at certain times of the year.

Through this plain may have meandered a river fed by the streams which flowed off the western and northern mountains, so that it was a strong and rapid river even though it may have received no affluent after leaving the gap between Ireland and Scotland. Such is the theory by which the accumulation of the "Pebble Beds" in the English Midlands has been explained, for the majority of these pebbles are quartzites which are unlike any

Welsh quartzites, but are identical with those found in the Old Red conglomerates of Scotland, the stones themselves having been originally derived from the Torridon sandstone.¹⁹

For a discussion of this matter the reader is referred to the author's *Building of the British Isles* (1911). Here it is only necessary to remark that these pebble beds do not signify more than a brief episode in the Bunter epoch; a few abnormally wet seasons would suffice to pile up all the pebbles which are now spread over Shropshire, Staffordshire, and Worcestershire. They had doubtless been accumulated in the higher tributary valleys of the river-system, and when heavy rains turned the streams of these valleys into rushing torrents, the pebbles were swept down into the main river, which, swollen by the floods, was strong enough to carry them for several hundred miles before they finally came to rest in a bay-like curve of the great plain, for the river must have flowed out westward into and across what is now the basin of the North Sea. There it was doubtless joined by other rivers, all combining to form a still larger one which curved southward and ran into the German lake or lagoon.

That the episode of the English Pebble Beds was not one of much physical importance is proved by the fact that it was followed by a reversion to the preceding conditions, for the Upper Bunter sandstone is so similar in character to the Lower sandstone that outside the area of the Pebble Beds it is difficult to distinguish them, and the sandy facies of the Pebble Beds merges outward into the Upper sandstone.

In Germany the characters of the Lower Bunter sandstone, its ripple marks, sun-cracks, and rain-prints, show that it was deposited in a large lake, probably of fresh water, and the Middle Bunter must be either lacustrine or terrestrial; but the case is different with the Upper Bunter, for its red gypsiferous marls are the deposits of saline water, and in Thuringia the inclusion of a marine limestone marks an incursion of the Southern Sea.

The epoch of the Bunter was brought to an end by a general subsidence of the whole region, the result of which was to bring the sea over the whole of the low-lying Germanic plain. This is the epoch of the Muschelkalk, and the higher level of the British area at this time is indicated by the fact that it was not reached by the Muschelkalk Sea. That sea passed over Hanover and the Island of Heligoland, and probably reached some distance farther west, terminating somewhere below what is now the bed of the North Sea.

Thus for a time the plains and lakes of the Bunter were converted into arms of the Southern Sea, and communication with

that sea was established across Bavaria, and perhaps also through Silesia to the east of the Bohemian Highlands. With regard to Russia little evidence is available, because any Triassic rocks which may exist in the western and central parts of that country are concealed beneath a thick cover of Jurassic and Cretaceous strata. In the Astrakan province, however, the Bogdo Mountains are capped by outliers of a limestone which is believed to be of Muschelkalk age, and beds belonging to the Upper Trias occur in the Crimea, so that it is very likely that the Southern Sea spread over a large part of Southern Russia during Muschelkalk time.

We have seen that a great thickness of rock-material was accumulated in this Southern Sea, and that as time went on the deposits formed therein became, at any rate in some parts, more and more calcareous. At the same time it does not seem to have been a deep sea, for apart from Molluscan shells (chiefly Lamellibranchs and Gastropods), the principal components of the limestones are calcareous algæ (*Diplopora* and *Gyroporella*), which at the present day do not flourish much below 150 fathoms. Hence, to account for the much greater mass of deposit in Austro-Alpine region, about 5000 feet as compared with 1000 in Germany, we must suppose that subsidence was more continuous in the southern than in the northern region.

The truth of this inference is confirmed by a consideration of the area where the German and Austrian facies of the Trias approach most nearly to one another. Between the Schwarzwald and Bohemia the German Keuper dips southward under the Jurassic strata of the great Danubian plain; while south of this plain, and cropping out from below the same Jurassic and Cretaceous rocks, are the highest members of the Austrian Trias, extending from the Vorarlberg to the Salzburg district. The breadth of this intervening tract, which conceals the passage of one facies into the other, between Tübingen and the Vorarlberg is only 100 miles.

There is no good reason for supposing that this tract conceals a ridge of Palæozoic rock, which could have formed a land-barrier between the two regions; it is much more probable that the one facies passes into the other with a comparatively rapid change, and the facts can be explained on the supposition that the crust-movements were of a counterpoising nature, the southern region continuing to subside while the northern at the beginning of Keuper time underwent a slight uplift with a north-west tilt, so that while the uplift was sufficient to cut off the northern area from the Southern Sea the inland waters were able to extend themselves farther west than those of the Muschelkalk had done.

In this manner was produced the great salt lake or inland

sea in which the red marls and salt deposits of the Keuper were formed; and judging from the relative thickness of the Keuper Series at different places the deepest parts of this inland sea were near Berlin in Germany (Sperenberg boring) and below Cheshire in England. In Fig. 124 I have attempted to restore the geography of Europe in the Keuper epoch, and though I have left an opening between Switzerland and Bohemia, this can only have been open during the time of the Kohlenkeuper, and must afterwards have been closed by local upheaval or in some other manner so as to shut out the waters of the Southern Sea from the northern basin.

The physical aspect of the country surrounding the inland sea must have combined the features of the Syrian desert around the shores of the Dead Sea with those of the country near the Caspian; that is to say, the Anglo-Germanic Sea was bordered in some places with rough and rocky hills, in others by sandy plains, and again in some places by reedy marshes and salt lagoons. We must not picture the whole region as completely barren and arid, for we know it was inhabited by various kinds of reptiles and Labyrinthodonts; moreover the continued existence of the lake would depend on the water-supply carried into it by rivers, though it is clear that this supply was often less than the amount which evaporated from its surface.

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CHAPTER XIII

THE JURASSIC SYSTEM

A. NOMENCLATURE AND DIVISION

IN the early days of Geology part of this system was called the "Oolitic Series" (by Conybeare and Phillips in 1822) from the prevalence of oolitic limestones in the central and upper parts of the system in England, and the Lias was described as a separate series; but on the Continent the equivalents of the former were called the "Jura limestones" by Brongniart and Boué in 1829 from the fact that beds of this age form the entire range of the Jura Mountains between France and Switzerland. In Germany the name "Jura" was adopted by von Buch for the whole system (1839), who divided it into Lower, Middle, and Upper Jura, and this nomenclature is still used in that country. It appears to have been d'Orbigny (1840-46) who first applied the term "Terrain Jurassique" to the whole succession, including the Lias; and at the same time he divided the system into a number of stages, but did not group these into series as von Buch had done.

The arrangement now generally adopted is a division into three series, which are practically those of von Buch, and a further subdivision into stages for which we in England have used local English names, while French geologists employ the latinised names proposed by d'Orbigny with some additions to their number. As a matter of fact it would be more convenient, and more in accordance with the nomenclature of older systems, to employ latinised names for the three great series themselves.^a

The English and French subdivisions are shown in the following table :—

^a For the Lower Series the
for the Middle Series I long
Roman name of Gloucester,
the Roman name of Weymo

in Lias or *Liasian* is already in general use ;
proposed¹ the name *Glevanian* from the
at of *Clavinian* for the Upper Series from

Upper Jurassic	{	Purbeck Beds	}	Portlandian.	
		Portland Beds		Kimmeridgian.	
		Kimmeridge clay		Sequanian.	
		Corallian Beds		Oxfordian.	
Middle Jurassic	{	Oxford clay	}	Bathonian.	
		Great Oolite		Bajocian.	
		Inferior Oolite		Toarcian.	
Lower Jurassic	{	Upper Lias	}	Charmouthian.	
		Middle Lias		Sinemurian.	
		Lower Lias and Rhætic		{	Hettangian.

It will be noticed that I follow French geologists in regarding the Rhætic or zone of *Pteria contorta* as the basal part of the Liassic Series, while the Germans have generally included it in the Trias. These beds were briefly referred to on p. 375, and reason was there given for restricting the name to this zone, which succeeds that of *Gervillia exilis* in the Eastern Alps but spreads far and wide beyond the latter over large parts of Europe. There is no doubt that it marks an epoch when the sea once more occupied the Triassic lowlands of Northern and Western Europe, and that over these lowlands it is a mere zone, from 30 to 40 feet thick, which is more intimately connected with the overlying Lias than with the underlying Keuper.

In dealing with the stratigraphy of this system it will be convenient to take each of the three great divisions or series separately, and to give a condensed account of the component strata of each series, both in Britain and on the Continent, before proceeding to the next one. We can afterwards review the general history of the whole period, and indicate the geographical changes which took place at its close.

B. LIFE OF THE PERIOD

The reader may be reminded that throughout Triassic times our islands formed part of a continent which occupied the northern part of Europe, and some part at least of the North Atlantic region, and that it was not until the Rhætic epoch that the inland lakes of this continent were finally submerged beneath the waters of an open sea. Further, the fauna of the British Rhætic beds or zone of *Pteria* [= *Avicula*] *contorta* in Northern Europe contains but a small number of species, and it was not till the time of the Lias that conditions were favourable for the establishment of a new and abundant marine fauna over the whole region. We are thus suddenly presented with an assemblage of fossils which is very different from those of the Carboniferous and Permian periods, and

for the ancestors of these we must search the marine Trias of Southern and Central Europe.

The rate of change in the organic world and the differentiation of species appears to have become much more rapid in Jurassic times than it had been in Palæozoic times, so that any given group of species has a much less vertical range, and consequently a much smaller set of strata requires separate description. It will, therefore, be convenient to describe the prevalent genera and the characteristic species of each series separately, but in the first place the distinguishing features of the Jurassic fauna as a whole may be indicated.

In the first place it was an "*age of Reptiles*," and it is specially characterised by the remarkable development of the orders *Dinosauria*, *Pterosauria*, *Ichthyopterygia*, and *Sauropterygia*. These orders survived into the Cretaceous period and then became extinct. The *Dinosauria* were land animals, and many were of gigantic size (from 30 to 70 feet long); in many cases their hind limbs were much longer and stronger than the fore legs, so that they could walk in an upright position like a kangaroo. Some were carnivorous (as *Megalosaurus*) and some herbivorous (as *Cetiosaurus*). The *Pterosauria* are reptiles adapted for the purpose of flight in the air, and thus possess many bird-like characters, such as pneumatic bones, keeled sternum, and more or less bird-like skull; their membranous wings were attached to the sides of the body and to the greatly elongated fifth digit. The *Ichthyopterygia* and *Sauropterygia* were specially adapted for life in the sea, both pairs of limbs being modified into the form of paddles or flippers. Representatives of the orders *Crocodylia* and *Chelonina* also occur.

Birds also make their appearance, but are known by two specimens only, found in the lithographic limestone at Solenhofen in Bavaria. They are referred to the genus *Archæopteryx*, which exhibits strong reptilian affinities, possessing teeth and a long narrow tail of twenty separate vertebræ, each of which apparently carried a pair of feathers; the wings are bird-like, and the creature was about the size of a common pigeon.

It is in Jurassic strata also that the earliest mammals have been found, and these all belong either to the sub-class Prototheria (which includes the living duck-billed mole, *Ornithorhynchus*, and the spiny ant-eater, *Echidna*) or to the sub-class Metatheria (which includes the opossums and kangaroos). No placental mammals have been found in the Jurassic System. Mammalian remains have been found at three horizons; the oldest (*Microlestes*) in the Rhætic Beds at the very base of the system, others (e.g. *Phasclotherium*, *Amphitherium*), in the Great Oolite, and others (10 genera, e.g. *Triconodon*) in the very highest group (Purbeck Beds).

Another special feature of the fauna is the great abundance and variety of the Ammonoid Cephalopoda. A few genera such as *Phylloceras* appeared in Triassic times, but a large number occur in Jurassic rocks, and many are confined to the period. The genus *Nautilus*, which also dates from the Triassic period, is the only representative of the Nautiloidea. *Belemnites*, a genus of Dibranchiate Cephalopods, appears in the Lias and reaches its maximum development in Jurassic times.

Gastropods are numerous, especially *Nerinea*, *Pleurotomaria*, *Cirrus*, *Pseudomelania*, *Natica*, and *Amberleya*.

Among Lamellibranchia the Ostreidæ, Pectinidæ, Limidæ, and Pholadomyidæ become abundant, and the genus *Gryphæa* is very characteristic of the period; *Trigonia* also is abundant.

Among Echinoderms the Euechinoid Group makes its appearance in England, and is very abundant both in species and individuals. The first irregular Echinoid is found in the Upper Lias. Some representatives of the Asteroidea, Ophiuroidea, and Crinoidea also occur. Corals also abound in most of the limestones.

Plants occur at several horizons, and Cycad-like fronds, stems, and "flowers" are so abundant that botanists have called the Jurassic period the "age of Cycads." The chief genera are *Zamites*, *Otozamites*, *Nilssonia*, *Pterophyllum*, and *Williamsonia*. Ferns continue to be common, and conifers were represented by genera allied to the modern *Araucaria*, *Cupressus* (cypress), and *Taxus* (yew).

The following are some of the genera which are not known in Britain or France before Lower Jurassic time, though some occur in the Alpine Trias. Those preceded by an asterisk did not survive the Jurassic period.

Anthozoa.—*Astrocænia*, **Heterastrea*, *Isastrea*, *Montlivaltia*, **Stylastrea*, *Thamnastrea*, *Thecosmilia*, *Trochocyathus*.

Echinoderma.—**Pentacrinus*, *Isocrinus*, *Ophioderma*, *Ophiolapis*, *Acrosalenia*, *Cidaris*, *Rhabdocidaris*, *Hemipedina*, *Pseudodiadema*.

Crustacea.—**Æger*, **Eryma*, *Eryon*, *Glyphæa*, *Penæus*, **Scapheus*.

Brachiopoda.—*Waldheimia*, *Thecidium*, *Terebratella*, *Cado-mella*.

Lamellibranchia.—*Astarte*, *Cardinia*, *Cardita*, *Cardium*, *Protocardia*, **Ceromya*, *Grammatodon*, *Cucullæa*, *Trapezium*, **Gresslya*, *Gryphæa*, *Velopecten*, **Hippopodium*, *Homomya*, *Inoceramus*, *Myoconcha*, *Opis*, *Ostrea*, *Plicatula*, *Perna*, *Pinna*, *Pholadomya*, *Goniomya*, *Pleuromya*, **Tancredia*, *Thracia*, *Trigonia*, *Unicardium*.

Gastropoda.—*Actæonina*, *Amberleya*, *Cerithium*, **Ceritella*,

*Cryptæna, Cyndrites, Dicroloma (= Alaria), *Exelissa, Littorina, Monodonta, Nerita, Neritopsis, Patella, Pseudomelania, *Purpurina, Solarium, Scalaria, *Trochotoma, Turritella.

Cephalopoda.—*Ægoceras, *Amaltheus, *Arietites, *Cœloceras, *Dactylioceras, *Deroceras, Harpoceras, *Haugia, *Hildoceras, *Grammoceras, *Liparoceras, Lytoceras, Holcostephanus, *Ophioceras, *Oxynoticeras, *Paltopleuroceras, *Phylloceras, *Psiloceras, *Schlotheimia, Belemnites.

Pisces.—Acrodus, *Dapedius, *Eugnathus, Hybodius, Lepidotus, *Leptolepis, *Pholidophorus.

Reptilia.—*Dimorphodon (a Pterodactyle), *Scelidosaurus (a Dinosaur), *Steneosaurus and *Pelagosaurus (Crocodiles), *Pliosaurus, Ichthyosaurus, Plesiosaurus, and Eretinosaurus (the last three, however, are represented in the Rhætic bone beds).

I. THE LIAS OR LOWER JURASSIC SERIES

A. THE BRITISH LIAS

Subdivisions.—This series has on the whole a very uniform lithological aspect throughout England. It consists almost everywhere of four successive sets of strata, and might with good reason be divided into four stages instead of the three which are usually adopted in England, for such a subdivision is not inconsistent with the range of the fossils, and is actually in use on the Continent (see table below). Thus (1) its lowest beds are more or less calcareous, and consist generally of thin-bedded limestones and shaly clays; (2) above these comes a thick mass of dark-grey clays; (3) these are succeeded by sandy clays and sandy limestone (marlstone); (4) while at the top are thin limestones and marly clays.

A further subdivision of the Lias into zones has resulted from a careful study of the distribution of its fossils. These zones are each characterised by one or more species of Ammonites, and though some of them are more or less local, and cannot be traced all across England, they can be grouped into nine principal zones which are so traceable. The following table shows the divisions in general use, the principal zones, and the continental divisions:—

Lithology.		Zones.	Cont. Equiv.
Upper Lias	{ Clays and thin limestones	Grammoceras aalense	} Toarcian.
		Dumortieria radians	
		Lillia Lilli	
		Grammoceras striatulum	
		Dactylioceras commune	
		Harpoceras serpentinum	

	Lithology.	Zones.	Cont. Equiv.
Middle Lias	{ Marlstones and sandy clays	{ <i>Paltoplcuroceras spinatum</i> <i>Amalthæus margaritatus</i>	{ Charnouthian.
Lower Lias		{ Clays	
	{ Limestones and clays		{ <i>Uptonia Jamesoni</i> <i>Oxynoticeras oxynotum</i>
			{ <i>Coroniceras Bucklandi</i> <i>Psiloceras planorbis</i>

With respect to the Upper Lias there has been much discussion and difference of opinion as to the horizon at which the line should be drawn between the Lower and Middle Jurassic Series. Where the two series are fully developed, as in the south-west of England, there is often a considerable thickness of sand between the Lias clays and the limestones of the Inferior Oolite, and as the sands were clearly passage-beds, some have included them in the Upper Lias, and others have grouped them with the Inferior Oolite.

The recent zonal work of Mr. S. S. Buckman has made it clear that the sands are not always on the same zonal horizon, but may be of any age from the *Lilli* to the *aalense* zone. It is also clear that they pass laterally into Upper Lias clays, and that they are as a whole more closely connected with the Lias than with the overlying Inferior Oolite. Moreover, in Yorkshire there is a distinct stratigraphical break between the two series, and it occurs at the base of the "Dogger" sandstone which overlies the zone of *Grammoceras aalense*. Hence it is convenient to place the divisional line at the summit of the zone of *Gram. aalense*, and to consider that of *Lioceras opalinum* as forming the base of the Middle Series.

By adopting this line we are in agreement with the Committee who drew up the scheme of the International Geological map of Europe, and in England it includes all the sands in the Lias except about 5 feet at the top of them near Bridport. In some localities several zones are condensed into a limestone bed of a few feet or even inches in thickness, and this happens sometimes with the lowest zones and sometimes with the highest.

Fossils of the Lower Lias

<i>Actinozoa.</i>	<i>Montlivaltia rugosa</i> , <i>Heterastrea Tomesi</i> .
<i>Echinodermæ.</i>	<i>Pentacrinus briareus</i> , <i>Isocrinus basaltiformis</i> , <i>Cidaris Edwardsi</i> .
<i>Brachiopoda.</i>	<i>Spiriferina Walcottii</i> , <i>Rhynchonella variabilis</i> , <i>R. rimosa</i> , <i>Waldheimia (Cincta) numismalis</i> .
<i>Lamellibranchia.</i>	<i>Pteria (Oxytoma) cygnipes</i> , <i>Cardinia Listeri</i> , <i>Gryphæa arcuata (= incurva)</i> , <i>Hippopodium ponderosum</i> , <i>Lima (Plagiostoma) gigantea</i> , <i>Pseudomonotis decussata</i> , <i>Ostrea liassica</i> .

Gastropoda.

Pleurotomaria anglica, *Cryptænia expansa*, *Amberleya elegans*.

Cephalopoda.

The following Ammonites characterise zones or sub-zones in ascending order: *Psiloceras planorbe*, *Schlotheimia angulata*, *Coroniceras Bucklandi*, *Arnioceras semicostatum*, *Arietites Turneri*, *Asteroceras obtusum*, *Oxynticeras oxynotum*, *Echioceras raricostatum*,

Fig. 125.—GROUP OF RHÆTIC FOSSILS.

a. *Protocardium rhæticum*.

b. *Pecten valoniensis*.

c. *Pteria contorta*.

d. *Myophoria postera*.

e. *Orbiculoidea Townshendi*.

f. *Ceratodus parvus*.

g. *Nemacanthus monilifer*.

Deroceras armatum, *Uptonia Jamesoni*, *Rhacoceras ibex*, *Ægoceras capricornus*, *Nautilus striatus*, *Belemnites acutus*, *B. elongatus*, *B. clavatus*.

Pisces.

Dapedius punctatus, *Hybodus reticulatus*, *Acrodus Anningæ*.

Reptilia.

Ichthyosaurus communis, *Plesiosaurus dolichodeirus*.

*Fossils of the Middle Lias**Echinoderma.*

Ophioderma Egertoni, *O. Milleri*.

Brachiopoda.

Rhynchonella tetrahedra, *R. acuta*, *Terebratula punctata*, *Waldheimia* (*Aulacothyris*) *resupinata*, *Waldheimia* (*Zeilleria*) *cornuta*.

Fig. 126.—LIASSIC AMMONITES.

a. *Dactyloceras commune* ($\frac{1}{2}$).
 b. *Harpoceras serpentinum* ($\frac{1}{2}$).
 c. *Egoceras capricornus* ($\frac{1}{2}$).

d. *Amaltheus margaritatus* ($\frac{1}{2}$).
 e. *Coronoceras Bucklandi* ($\frac{1}{2}$).
 f. *Psiloceras planorbe* ($\frac{1}{2}$).

Lamellibranchia. Pteria (Oxytoma) inæqualvis, Protocardia truncatum, Gresslya intermedia, Lima punctata, Modiola scalprum.

Gastropoda. Trochus lineatus.

Fig. 127.—GROUP OF LIASSIC FOSSILS.

- a. Pseudomonotis decussata.
- b. Gryphaea arcuata.
- c. Hippopodium ponderosum.
- d. Pleurotomaria anglica.
- e. Belemnites elongatus.

- f. Dactylioceras communis.
- g. Nautilus striatus.
- h. Lima gigantea.
- m. Leda ovum.
- n. Rhynchonella tetrahedra.

Cephalopoda. Amaltheus margaritatus, Paltoleuroceras spinatum, Lytoceras fimbriatum, Belemnites paxillosus.

Reptilia. Pliosaurus propinquus.

Fossils of the Upper Lias

- Echinoderma.* Pentacrinus jurensis.
Brachiopoda. Rhynchonella jurensis, Waldheimia (Cincta) Lycetti,
 Discini reflexa, Cadomella Moorci. ver 18
Lamellibranchia. Inoceramus dubius, Gresslya donaciformis, Leda ovum,
 Pecten pumilus, Posidonomya Bronni.
Gastropoda. Trochus lineatus.

Fig. 123.—GROUP OF LIASSIC FOSSILS.

a. Otopteris obtusa.	d. Spiriferina Walcottii.
b. Pentacrinus briareus.	e. Waldheimia numismalis.
c. Ophioderma Egertoni.	f. Rhynchonella rimosa.

- Cephalopoda.* Harpoceras serpentinum, Harp. aalense, Harp. striatulum, Daetylioceras commune, Hildoceras bifrons, Dumortieria radians, Belemnites abbreviatus, B. Voltzii.
Pisces. Lepidotus elvensis (= gigas), Leptolepis concentricus.
Reptilia. Ichthyosaurus acutirostris, Steneosaurus Chapmanni.

Stratigraphy.—The Lias occupies the coast of Dorset from Lyme Regis to Bridport harbour, it stretches inland to Ilminster,

Petherton, and Yeovil, and thence passes northward to the Mendip Hills, where all the divisions become very thin. North of Bristol

Fig. 120.—TWO MARINE REPTILES FROM THE LOWER LIAS.

A. *Ichthyosaurus communis*.

B. *Plesiosaurus dolichodeirus*.

it thickens again and forms a broad tract running through the counties of Gloucester, Warwick, Northampton, Leicester, Lincoln,

and York. Another fine coast section is exposed in the cliffs of the Yorkshire coast between Redcar and Whitby.

Outlying tracts of Lias occur in Staffordshire, at Needwood Forest and north of Abbots Bromley; in Shropshire, between Wem and Audlem, and in Cumberland, near Carlisle, proving that the formation originally extended far to the north-west of its main line of outcrop. There is little doubt, indeed, that the Lias was once coextensive with the Trias, but there is no indication that it ever extended very far beyond the limits of the Keuper marls.

In Ireland Liassic rocks crop out in certain places from beneath the Cretaceous rocks of Antrim, and in Scotland remnants of Lias occur above the Trias on the west coast and on the east coast of Sutherland.

With regard to the eastward subterranean extension of the Lias in England, it is known that its upper beds, as they pass beneath the higher members of the Jurassic System, thin very rapidly. Thus in a boring at Burford, in Oxfordshire, the Middle and Upper Lias are together less than 30 feet thick; the Lower Lias is there about 620 feet thick, and the Rhætic is 10 or 12 feet; but between that place and Richmond the Lias has wholly disappeared, allowing rocks of the Middle Jurassic Series to rest directly on rocks which are either of Triassic or of Old Red Sandstone age. It would appear, therefore, that between Richmond and the Malvern Hills the width of ground now occupied by the Lias is less than 100 miles. No trace of Lias has been found in any of the deep borings that have been made in the eastern counties. Northward it may underlie part of Cambridgeshire, but it thins out beneath Suffolk, a boring at Culford, near Bury St. Edmunds, having proved Cretaceous Beds to rest directly on the Palæozoic rocks.

The chief zonal and provincial features of the British Lias may be indicated under the head of four provincial areas: (1) the south-west province, including Dorset, Somerset, Gloucester, and Glamorgan; (2) The Midland Counties from Oxfordshire to the Humber; (3) Yorkshire; (4) Cumberland, Ireland, and Scotland.

1. *The South-West Province*

An excellent section of the whole Liassic Series is exhibited in the cliffs of the south coast of Dorset, from Lyme Regis on the west to Bridport on the east (see Fig. 130), and this may be regarded as the typical section of the English Lias, though some of the zones in the Lower Lias are not so fully developed as they are in the Midlands.

FIG. 130.—SECTION ALONG THE DORSET COAST FROM LYME REGIS TO BURTON BRADSTOCK (H. B. Woodward). Distance about 30 miles.

- 14. Cretaceous (Selbornian).
- 13. Forest marble.
- 12. Fuller's Earth.
- 11. Inferior Oolite.

10. Yeovil sands.
9. Upper Lias clay.
8. Sands of Middle Lias.

- 6 and 7. Middle Lias.
5. Green Ammonite Beds.
4. Belemnite Beds.
3. Black shales.
2. Blue Lias.
1. Rhaetic Beds.

Lower Lias.—The succession of beds which constitute the Lower Lias at Lyme Regis is as follows in descending order :—²

	Feet.
Green Ammonite Beds { Bluish-grey marly clays with <i>Rhacoceras Loscombei</i>	105
{ Bluish-grey marly clays with <i>Platypleuroceras latocosta</i>	
Belemnite Beds { Pale-grey marls with some marly limestones ; few fossils	80
Black Shales { Shaly marls with <i>Echioceras raricostatum</i>	15
	15
	170
Blue Lias { Shales and marls with <i>Arnioceras semicostatum</i>	18
	67
	20
	25
Rhætic Beds { "White Lias," limestones, and shales	32
	30
	577

The Rhætic Beds are exposed to the west of Lyme Regis at Charton Bay and Culverhole (see Fig. 131). Throughout Dorset and Somerset there are a set of passage-beds between the Keuper marls and the Rhætic Beds, and these have recently been called the Sully Beds by Mr. L. Richardson.³ The base of the *Pteria contorta* zone is marked by a layer of calcareous grit full of the bones and coprolites of fish and small reptiles ; this is also of general occurrence, and is known as "the bone bed." In the White Lias or Upper Rhætic *Ostrea liassica* and *Modiola minima* are the commonest fossils.

The succession of zones and sub-zones is normal up to that of *Ech. raricostatus*, but above that the typical Ammonites are rare. The Belemnite Beds are supposed to represent the *armatum*, *Jamesoni*, and *ibex* zones, but the two latter species of Ammonites do not occur. The succeeding beds may be regarded as the equivalent of the zone of *Ægoceras capricornus*, and its sub-zone of *Æg. Henleyi*.

In Somerset the beds forming the Lower Lias are similar to those of the Dorset coast, but the higher zones are seldom exposed. Near Watchet on the Bristol Channel there is a good section of Rhætic Beds (Black Shales and White Lias, 46 feet) and of Lower Lias for about 150 feet, including the *planorbe*, *angulatum*, *Bucklandi*, and *semicostatum* zones.

The limestones of these lower zones have been quarried at many places from Ilminster eastward, and are upwards of 200 feet thick,

Fig. 131.—SECTION FROM NEAR AXMOUTH TO LYME REGIS. Horizontal scale, 1 inch to a mile.

1. Keuper marls.
3. Lower Lias.
2. Rhaetic Beds.
5. Middle and Lower Chalk.
4. Selbormian sands.

Fig. 132.—SECTION IN THE CLIFFS ON THE EAST SIDE OF RAASAY (by Professor Judd, *Quart. Journ. Geol. Soc.* vol. xxxiv.)

- m. Eocene lava-flow.
- h, i. Shales and sandstones (Great Oolite).
- h. Sandstones and shales (Inf. Oolite).
- g. Upper Lias.
- f. Middle Lias.
- d, e. Lower Lias.
- c. Rhaetic and Lower Lias.
- b. Triassic sandstone.
- a. Torridon sandstone.

about half of this belonging to the *planorbe* zone and the rest to those of *Schlotheimia angulata* and *Coroniceras Bucklandi*. The quarries at Queen Camel and Street have yielded many fine specimens of *Ichthyosaurus*, *Plesiosaurus*, fish, and other fossils, and at the base are shaly limestones which contain remains of insects and Decapod Crustacea (*Eryon*).

Evidence that the higher zones persist is found in the occurrence of the Ammonites *semicostatus*, *obtusus*, and *oxynotus*, but it is doubtful if the Lower Lias in Somerset is more than 400 feet thick.

Northwards, however, there is a rapid thinning, so that at Shepton Mallet the same four zones have a thickness of only 33 feet, overlain by 36 feet of clays and limestones referable to the *obtusum* and *oxynotum* zones. Round the Mendip Hills there are only irregular patches of limestone and clay to represent the whole of the Lower Lias. To the north of the Mendips, however, it soon regains its normal aspect and thickness.

Westward, in South Wales, there are fine exposures of the lower beds in the cliffs between Penarth and Dunraven Castle. At Penarth there is a normal sequence of Rhætic Beds with a thickness of about 40 feet, and above them are the usual limestones and shales for 135 feet, but when followed westward they exhibit a remarkable lithological change.

The Rhætic Beds first pass into a massive oolite, and finally, near Bridgend and Pyle, into pale-green and yellow sandstones with a medial band of green marls, shales, and limestones, the whole being from 40 to 50 feet thick. The shales and limestones of the overlying Lias pass westward into massive pale-coloured marly limestones which overlap the Rhætic sandstones so as to rest, with a conglomerate base, on the Carboniferous limestone at Sutton and Brocastle near Bridgend. In these beds are corals of the genera *Astrocenia*, *Montlivaltia*, and *Thecosmia*, together with *Pseudomonotis fallax* and *Ostrea liassica*. Ammonites are scarce, but the higher beds contain *Schlotheimia angulata*, *Arietites Bucklandi*, and *Arnioceras semicostatum*.

Middle Lias.—On the Dorset coast this division is exposed in the cliffs between Charmouth and Bridport, and presents the following succession :—

		Feet.
Zone of <i>Palt. spinatum</i>	{ Ferruginous limestone (marlstone)	1
	{ Yellow sands and sandy clays	77
Zone of <i>Amal. margaritatus</i>	{ Laminated micaceous sands and clays	72
	{ Blue micaceous clays with limestone nodules	160
	{ "Three tiers" of calcareous flagstone with sandy clays between	35
		<hr/>
		345

The blue clays contain *Amaltheus margaritatus*, *Belemnites elongatus*, *Plicatula spinosa*, etc., and at their summit is a bed of calcareous sandstone known as the Starfish Bed, from its having yielded two species of *Ophioderma*. The Marlstone is here very thin.

When followed northward into Somerset the whole group becomes thinner, its thickness near Glastonbury being little over 200 feet, but still having a bed of Marlstone rock at the summit, from 1 to 2 feet thick. Round the Mendip Hills the Middle Lias becomes very attenuated, and is represented sometimes by a few feet of marly shale, and sometimes by conglomerate resting directly on Carboniferous limestone; in other places it is overlapped by the Inferior Oolite.

Towards Bath the normal succession is again found, but with a thickness of only 50 or 60 feet. Northwards through Gloucestershire the beds thicken considerably, till near Stinchcombe the Marlstone is 15 feet, and the underlying sands and clays are about 150. The Marlstone here forms a conspicuous rock-bed which is often quarried. It contains *Paltopt. spinatum*, *Belemnites paxillosus*, *Rhynch. tetrahedra*, *Pecten equivalvis*, and other fossils.

Upper Lias.—In Somerset and Dorset this stage may be described as consisting of three unequal portions (1) the Junction Bed, (2) the Upper Lias clays, (3) the Upper Lias sands. The first is a bed of pale-grey argillaceous limestone ($1\frac{1}{2}$ to $2\frac{1}{2}$ feet thick), which is welded to the top of the Marlstone and contains in successive layers the characteristic species of three zones, viz.—*Harpoceras falciferum*, *Hildoceras bifrons*, and *Harpoceras striatulum*. The clays or shales are about 70 feet thick and contain but few fossils, but species of *Dumortieria* have been found in them. They pass up into fine yellow sands containing large burrstones or lumps of calcareous sandstone. Of such sand there is nearly 200 feet, but most of it yields no fossils; between 40 and 50 feet from the top a band contains *Dumortieria radians* and *D. Moorei*, and then come 30 feet with species of the *Harpoceras aalensis* type, and these are succeeded by about 5 feet of sand with *opalinoid* forms, so that the passage from one stage to the other here takes place very near the top of the sands.⁴

In Somerset, near Yeovil, there is a similar succession, but the base is formed by a band of shaly clay containing many small Brachiopoda such as *Leptaena Moorei*, *L. Bouchardi*, and *Zellania liassica*. This is overlain by a bed of limestone with *Harp. falciferum*, and remains of fish, crustacea, and insects. Above are blue clays succeeded by sands with Ammonites of the *radians* type (*Dumortieria*), and in the higher part of these sands a

lenticular mass of oolitic freestone is developed with a local thickness of 80 feet and containing *Dum. Moorei*; this is known as the Ham Hill Stone.

Northward the sands thin out entirely, so that near Bath the *radians* zone is represented entirely by clay, but is underlain by sands which Mr. Buckman assigns to a sub-zone intermediate between that of *Lilli* and that of *radians*, and at its base there is a condensed limestone representing lower zones.

In Gloucestershire there is another change and a different succession: (1) clays representing the *falciferum* and *bifrons* zones; (2) the Cotteswold sands, which include the zones of *Harp. Lilli* and *H. variabilis*; and finally a Cephalopoda Bed representing all the higher zones in successive layers of limestone. The clays vary from 50 to 130 feet, the sands are on the average 150 feet, and the limestone varies from 2 to 8 feet.

2. The Midland Counties

Rhætic Beds.—These form a narrow but continuous band between the Keuper marls and the dark shaly clays of the Lias, but they are rarely exposed in Worcester. In Warwickshire there are exposures of the White Lias at Knowle (near Solihull) and at Harbury, Rugby, Southam, and Easington, and a good section has been described at Wigston, near Leicester, where the following succession was seen:—

	Feet.
2. Blue shales with two thin beds of limestone and sandstone	22
1. Black shales containing <i>Schizodus cloacinus</i> , <i>Protocardium rhaticum</i> , <i>Pteria contorta</i> , and fish teeth	18

A similar succession is found in Rutland and Lincolnshire.

The Lower Lias is seldom well exposed in Oxfordshire or Warwickshire, but a boring has proved its thickness to be 450 feet, and fairly good sections are found near Harbury and Fenny Compton, where all the zones are seen except those of *oxynotum* and *armatum*.

In the counties of Leicester, Rutland, and Lincoln the Lower Lias is both more accessible and more fully developed, and the following succession of beds has been described:—

Lower Lias, B	(Blue clays with septaria (<i>Egoceras capricornus</i>).
	(Blue clays with thin limestones and septaria (<i>Rhacoceras ibex</i> and <i>Uptonia Jamesoni</i>).
	(Sandy clays and sands, occasionally indurated into a stone (<i>Deroceras armatum</i>).
	(Blue clays with small septaria (<i>Oxynoticeras oxynotum</i>).

Lower Lias, A	{	Ferruginous limestones with <i>Arnioceras semicostatum</i> .
		Blue clays and grey limestones (<i>Coroniceras Bucklandi</i>).
		Dark-blue pyritous clays (<i>Schlotheimia angulata</i>).
		Limestone and shales (<i>Psiloceras planorbe</i>).

The zones of *planorbe*, *angulata*, and *Bucklandi* present the same features as elsewhere, and have a combined thickness of about 200 feet. They are succeeded by several beds of hard ferruginous limestone with interbedded shales (the *semicostatum* zone), which thicken northward till they are 27 feet thick at Scunthorpe and Frodingham, where they are worked for ironstone.

The upper part (B) of the Lower Lias is about 470 feet thick in the Vale of Belvoir, and a boring at Grantham showed the Lower Lias as a whole to be about 700 feet thick. The *obtusum* zone is thin or absent, but clays with *oxynotum* and *raricostatum* occur, and are about 90 feet thick. Northwards, however, the thickness diminishes. The lower zones (A) maintain their thickness, but the zones of *oxynotum*, *armatum*, and *Jamesoni* are represented by clays from 100 to 140 feet thick, surmounted by a bed of ironstone about 4 feet thick, which is known as the "Pecten Bed," from the abundance of several species of *Pecten*. This bed contains a mixture of Lower and Middle Lias species, and is by some regarded as the base of the Middle Lias, but its Ammonites are *armatum*, *Henleyi*, and *striatum*, while the clays above it contain *Ægoceras capricornus* throughout and not *Amaltheus margaritatus*. These clays are about 70 feet thick, and consequently the total thickness of Lower Lias in this district is from 400 to 440 feet.

Middle Lias.—In the counties of Oxford and Warwick the Middle Lias is about 150 feet thick, and Mr. H. B. Woodward⁵ remarks that "the Marlstone Rock-bed is perhaps nowhere better developed than in the country around Banbury. It covers an extensive area to the north-west, forming a plateau that rises gradually from about 500 feet at Banbury to the escarpment of Edge Hill, 710 feet high, and this area is intersected by several deep valleys." The Marlstone consists of more or less ferruginous and sandy limestone, which varies from 12 to 25 feet in thickness. The outer parts are always brown from the oxidation of the iron, but the centres of large blocks are generally grey. The commonest fossils are *Terebratula punctata* and *Rhynchonella tetrahedra*, which often occur in clusters.

Upper Lias.—This division is well developed in Northamptonshire, where it has been studied and described by Mr. B. Thompson.⁶ He divided it into 8 zones, but the highest of these forms a passage into the overlying series, and would perhaps be better included in the latter; his 7th zone is a nodule bed at the

base of this, so that the restricted Upper Lias would consist of the following :—

	Feet.
Leda Ovum Beds (zone of <i>Am. Lilli</i>)	36
Cerithium Beds (<i>Cerithium armatum</i>)	36
Zone of <i>Dactylioceras fibulatum</i> and <i>Hildoceras bifrons</i>	76
„ <i>Dactylioceras subcarinatum</i> (Commune Beds)	5
„ <i>Harpoceras falciferum</i> (Serpentinum Beds)	4
„ <i>Am. lateicens</i> (Fish Beds)	2
	<hr/>
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A similar set of beds is found in Rutland, but in Lincolnshire the highest beds seem to have suffered erosion before the deposition of the overlying sandstone, and the highest remaining part of the Lias belongs to the *bifrons* zone. On the other hand the *serpentinum* Beds thicken northward to about 40 feet, and the total thickness of the stage at Lincoln is about 100 feet.

3. Yorkshire

In the south of Yorkshire, from Brough to Kirby Underdale and Howsham, the Lias is similar in all respects to that of North Lincoln, but as soon as the valley of the Derwent is crossed a change begins to be manifest, both the Middle and Upper Lias swelling out till they again attain a development equal to that of South Lincolnshire. From Howsham the outcrop curves round by Thirsk and Northallerton to the coast between Redcar and Whitby, which exhibits an excellent section of the whole formation except the zone of *Psiloceras planorbis*.

The following is a résumé of the coast section :—⁷

Upper, 330 feet	{	Blea Wyke sands with <i>Harpoceras aalensis</i> , 50 feet.
		Blue shales, with <i>Harp. striatulum</i> and <i>H. variabilis</i> , 70 feet.
		“Alum shales” with <i>Dactylioceras commune</i> , <i>Hildoceras bifrons</i> , and <i>Leda ovum</i> , 90 feet.
		Blue shales with calcareous doggers and layers of jet in the lower part. <i>Harpoceras serpentinum</i> , <i>Belemnites tubularis</i> , <i>Inoceramus dubius</i> , 90 feet.
Middle, 140 feet	{	Grey shales with <i>Dactylioceras annulatum</i> and <i>Belemnites cylindricus</i> , 30 feet.
		Ironstone (Cleveland main seam) and shales below, zone of <i>Amaltheus spinatus</i> , 20-50 feet.
		Ironstone (lower seam) or Pecten Bed, with beds of marly sandstone below; contains <i>Amaltheus margaritatus</i> and <i>Pecten levis</i> , about 100 feet.

Lower, 714 feet	{	Clays with <i>Egoceras capricornus</i> , 130 feet.
		Shaly micaceous clays with <i>Uptonia Jamesoni</i> , 225 feet.
		Clays with <i>Asteroceras obtusum</i> , <i>Oxynoticeras oxynotum</i> , and <i>Echioceras raricostatum</i> , 100 feet.
		Shales and limestones with <i>Arietites Turneri</i> and <i>Arnioceras semicostatum</i> , 66 feet.
		Shales and thin limestones, zone of <i>Arietites Bucklandi</i> , 113 feet.
		Shales and thin limestones, <i>Schlotheimia angulata</i> , 30 feet. Zone of <i>Psiloceras planorbe</i> below, but not accessible (? 50 feet).

Mr. R. H. Rastall has shown⁸ that it is only at Blea Wyke on the coast that a complete passage from Lias to Inferior Oolite is seen. At other localities the ferruginous sands which form the base of the latter (see p. 420) rest upon an eroded surface of the Lias and usually upon some part of the *commune* zone. In many places currents have cut channels in the Lias, and these are often filled with sand at the base of which is a layer of pebbles and phosphatic nodules.

4. Cumberland, Ireland, and Scotland

These areas may well be considered together, for there can be no doubt that the Liassic Series was originally continuous across the seas which now divide them.

Lower Lias.—It is interesting to find an outlier of Lias in the Carlisle basin, because it confirms the view that the northern Pennine Hills were not then in existence, but were part of the Triassic plain which became first the floor of the Keuper Lake and subsequently that of the Liassic Sea. It is believed, however, that the Rhætic Beds are absent, and that the zone of *Psil. planorbe* rests unconformably on the Keuper marls. The whole country is covered with glacial drift, so that there are few exposures, but a boring near Great Orton passed through 210 feet of dark shales with bands of limestone in the lower part.

In Ireland the Lower Lias is found at intervals along the coast of Antrim between the Trias and the Cretaceous rocks, but is frequently cut out by the overstep of the latter. The zone of *Pteria contorta* is well developed, the lower part consisting of grey shales and sandstones with fish remains, the middle of black shales with the usual fossils, and the upper of grey shales with layers of oolitic limestone, and the whole is about 80 feet thick. These beds are succeeded by Lower Lias with the same lithological facies as in England, but the series is cut off in or above the zone of *Echioceras semicostatum*.

The mapping of the Isle of Arran by the Geological Survey

revealed the fact that a similar succession of beds existed there in Tertiary times, for in the conglomerate which fills a large volcanic orifice or neck (see p. 368) fragments and tabular masses of Rhætic and Liassic limestones were discovered, the fossils found in them leaving no doubt about the age of the rocks.

Farther north on the coast of Argyleshire and in the islands of Mull, Skye, and Raasay, a nearly complete succession of Liassic deposits is found, which differ in several respects from those of England. They were fully described by Professor Judd in 1878,⁹ from whose account the following is mainly taken.

The Rhætic zone is thin and seems to be represented by about 8 feet of calcareous sandstones, limestones, and shales. The overlying beds are very hard bluish-grey limestones, alternating with calcareous grits and conglomeratic sandstones. The commonest fossil is *Ostrea irregularis* (a variety of *O. liassica*), but corals *Thecosmilia Martini* and *Isastrea Murchisoni* also occur, together with *Cardinia concinna* and spines of *Acrosalenia*. Ammonites are not found, but the beds may be regarded as equivalent to the *planorbis* and *angulatum* zones; their thickness is about 200 feet, and they are well seen at Applecross and on the opposite coast of Raasay (see Fig. 132).

The succeeding zone of *Arietites Bucklandi* is well developed, and consists of shelly limestones and shales crowded with fossils of the same species which are common in England; its thickness is 250 feet. Above are dark micaceous shales containing *Arn. semicostatum*, *Asteroceras Brooki*, and *Belemnites acutus*, 150 feet. The separate existence of the *oxynotum* zone is not determined, the fossils of this zone only occurring at Tobermory in Mull, where they are mingled with others that belong to higher horizons.

The higher part of the Lower Lias consists of sandy and micaceous shales called the Pabba shales by Professor Judd. At the base of these there are some beds in which *Deroceras armatum* occurs, but the greater portion of the group represents the zones *Jamesoni* and *capricornus*; these shales contain *Uptonia Jamesoni*, *Platypleuroceras brevispina*, *Deroceras Davæi*, *Modiola scalprum*, and *Gryphæa cymbium*, and are about 250 feet thick.

In the north-east of Scotland beds of Liassic age occur in the reefs below Dunrobin Castle on the Sutherland coast. Here the basement beds consist of coarse sandstones and conglomerates, containing fragments of the cherty rock mentioned on p. 369. These beds are succeeded by a remarkable set of estuarine deposits, consisting of sandstones and shales with thin layers of clay and coal, the whole attaining a thickness of between 400 and 500 feet; no fossils have been found except in the uppermost beds,

where a few dwarfed *Gryphæa* and *Cardinia* prove the occasional presence of salt water. As these beds are overlain by clays with *Oxynticeras oxynotum*, they must be the estuarine equivalents of the *planorbe* and *Bucklandi* zones.

The overlying marine beds exhibit the following succession :—¹⁰

	Feet.
3. Dark-blue micaceous clays with septaria, <i>Belemnites acutus</i> , <i>Platyleuroceras brevispina</i> , <i>Uptonia Jamesoni</i> , <i>Hippopodium ponderosum</i> , and <i>Gryphæa cymbium</i>	80
2. Micaceous sandstones and clays with <i>Gryphæa obliquata</i> , <i>Pecten æquivalvis</i> , and <i>Belemnites acutus</i>	34
1. Blue clays and impure limestones with <i>Oxynticeras oxynotum</i> , <i>Arnioceras caprinus</i> , <i>Bel. acutus</i> , <i>Cardinia hybrida</i> , <i>Lima pectinoides</i> , and <i>Gryphæa obliqua</i>	60

Middle Lias.—There can be little doubt that deposits of this age succeeded the Lower Lias over the whole region of the Irish Sea and the Hebridean Sea, but the only remnants of them which have escaped destruction are in some of the Western Isles. Here they are shallow-water deposits, consisting chiefly of sandstones. They are well exposed in Scalpa and Raasay, where grey calcareous sandstones, with some beds of calcareous shale, have a thickness of 200 feet. They contain such characteristic fossils as *Amaltheus margaritatus*, *Paltoleuroceras spinatum*, *Belemnites acutus*, and *Rhynch. tetrahedra*. In Mull they are represented by soft greenish sandstones with few fossils.

In Sutherland no such beds are exposed *in situ*, but their former existence is proved by the occurrence of boulders of calcareous sandstone, like those of the western coast, in the boulder-clays of Moray and Elgin. These boulders enclose such fossils as *Belemnites paxillosus*, *Modiola scalprum*, *Pteria inæquivalvis*, and *Panopæa elongata*, and others which occur in the Scalpa sandstones of the west coast. It is quite possible indeed that such rocks (of Marlstone age) may still exist *in situ* beneath the vast masses of glacial clay which mantle the surface of Elginshire.

Upper Lias.—This also is only found in the Western Isles, where it presents the usual shaly facies with much pyrites and jet; the lower portion yields *Harpoceras serpentinum* and *Dumortieria radians*, and the upper beds *Dactylioceras commune*, with *Belemnites Voltzi* and *Posidonomya Bronni*. Sections are generally obscured by slips and grass, but the thickness averages from 75 to 80 feet.

B. CONTINENTAL LIASSIC STRATA

Jurassic rocks form a nearly complete ring round the great Cretaceous basin of the north of France, the continuity of their

outcrop being interrupted only in the north-east where they are concealed beneath the overstepping Cretaceous deposits between the Ardennes and the Boulonnais. It is unnecessary to burden the student with details of the local variations exhibited by the Lias in this and other parts of France, and it will suffice to give a brief account of its development on the eastern borders of the country in Alsace, Lorraine, and the Jura district, while the very different facies found in Provence will be referred to under the head of the Alpine region.

French geologists divide the Liassic Series into five stages, making the Rhætic one of them, but as it has really only the value of a zone it is better to include it in the overlying stage (Hettangian). If this is done we have the following stages in descending order :—

4. *Toarcian*. Zones of *jurensis*, *communis*, and *falciferum*.
3. *Charmouthian*. Zones of *spinatum*, *margaritatus*, *capricornus*, and *armatum*.
2. *Sinemurian*. Zones of *ruricostatum*, *obtusum*, *Turneri*, and *Bucklandi*.
1. *Hettangian*. Zones of *angulata*, *planorbe*, and *Pteria contorta*.

The French also include the zone of *Lioceras opalinum* in their Toarcian, but the Germans do not, and in England its equivalent is usually regarded as the base of the Inferior Oolite.

How far the Hettangian zones extend under the Paris basin is unknown, but probably all the higher stages are continuous beneath that basin and the English Channel, passing into their equivalents in the south of England. The Upper Lias has recently been reached by a deep boring at Rouen.

Hettangian.—This takes its name from Hettange in the south of Luxemburg, in which district this part of the series has an unusual thickness because it consists largely of estuarine beds, as below :—

		Feet.
Lias	{ Sandstone with marine shells and plant remains	200
	{ Black clays and black limestones	30
Rhætic	{ Red clays with one or more bone beds	18
	{ Yellow micaceous sandstones	25 to 30

The black beds contain few fossils, but must represent the zone of *Psiloceras planorbe*, and the Hettange sandstone that of *Schlotheimia angulata*. In Alsace and Lorraine the Rhætic presents a similar facies and maintains a thickness of from 30 to 40 feet, but both the zones of *Psiloceras planorbe* and *Schlotheimia angulata* are so thin as to be scarcely recognisable.

Sinemurian.—In the north-east of France this stage consists principally of grey limestones in regular beds full of *Gryphæa arcuata*,

so that they are known as the "*calcaire à Gryphées*," but they also contain *Coroniceras Bucklandi*, *Arnioceras bisulcatum*, and other fossils. These beds are from 100 to 130 feet thick, and are overlain by some 80 feet of unfossiliferous shales which occupy the place of the higher zones.

Charmouthian.—In Alsace and Lorraine this stage consists mainly of calcareous marls with ferruginous nodules, surmounted by hard limestones with *Paltoleuroceras spinatum*, the whole being about 200 feet thick. To the north-west in Luxemburg and the Ardennes the lower beds become sandy, and near Mezières the succession, according to Professor Gosselet, is as follows :—

	Feet.
Ferruginous limestone with <i>Paltoleuroceras spinatum</i> .	130
Marls with <i>Bel. clavatus</i> and <i>Egoceras capricornum</i> .	160
Sandy limestone with <i>Microceras planicostum</i> . . .	60
	<hr/> 350

Toarcian.—In Alsace and Lorraine this group consists in the lower part of bituminous shales full of *Posidonomya Bronni*, but also yielding *Hildoceras bifrons* and *Harpoceras falciferum*; the higher beds are marls with *Lytoceras jurense* from 10 to 12 feet thick, while the shales below vary from 30 to 160 feet.

The details of the Toarcian have been more fully worked out in Normandy by Messrs. Brasil and Buckman,¹¹ who have recognised all the Dorset sub-zones, though the whole stage is only 32 feet thick and consists entirely of shales and clays. It is directly overlain by limestone with *Lioceras opalinum*.

In the district of the Jura Mountains the Liassic Series is not so fully developed as the higher parts of the Jurassic System, but the whole of it is exposed in different places and has the following composition :—

	Feet.
<i>Toarcian</i> . Marls and <i>Posidonia</i> shales	150
<i>Charmouthian</i> . Marls with <i>Belemnites</i>	100
<i>Sinemurian</i> . Blue clays and <i>Gryphæa</i> limestones	60
<i>Hettangian</i> . Limestones	6
<i>Rhaetic</i> . Sandstones, marls, and limestones with a bone bed at the base	50
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1. Germany

The Lias is chiefly exposed in the south of Germany, its outcrop extending in a long strip from the foot of the Black Forest on the west through Swabia and then curving northwards by Nuremburg to Bamburg, Coburg, and Baireuth. In this area it has been

studied by Oppel, Quenstedt (1850-88), Struckmann (1881), Waagen (1864), and Stuber (1893). Its thickness is here comparatively small, but most of the zones established in England and France have been recognised, and the general succession of beds is as follows :—

Upper,	{ Grey marls with <i>Lytoceras jurense</i> .
30 feet	{ Bituminous shales with <i>Posidonomya</i> .
	{ Limestone with <i>Paltoleuroceras spinatum</i> .
Middle,	{ Clays with <i>Amaltheus margaritatus</i> .
100 feet	{ Hard marls with <i>Deroceras Davxi</i> .
	{ Clays with <i>Rhacoceras ibex</i> and <i>Uptonia Jamesoni</i> .
	{ Clays with <i>Asteroceras obtusum</i> and <i>Oxynoticeras oxynotum</i> .
Lower,	{ Bituminous shales and <i>Pentacrinus</i> Beds.
120 to	{ Limestones with <i>Gryphaea</i> and <i>Coroniceras Bucklandi</i> .
140 feet	{ Sandstones with <i>Schlotheimia angulata</i> .
	{ Limestones with <i>Psiloceras planorbe</i> .
	{ Rhætic sandstones and shales (20 to 40 feet).

In Northern Germany there are irregular outcrops of Lias along a tract extending from the Teutoburger Wald eastward through the south to Hanover and Brunswick; the component beds being very similar to those of Swabia and Franconia. Moreover, it appears to extend northward and north-eastward below the great plains of Hanover and Prussia, for its existence has been proved by a boring at Hermsdorf near Berlin and by another at Kammin in Pomerania.

2. Sweden

The Lias recurs on the north side of the Baltic in Scania, where the Rhætic position has an estuarine facies, consisting of a series of sandstones, shales, and clays with beds of lignitic coal and of clay ironstone; in fact a "carboniferous" facies, with a thickness of about 300 feet. Plant remains are very abundant, including species of *Camptopteris*, *Lepidopteris*, *Thaumatopteris*, *Nilssonia*, and *Dictyophyllum* with many Cycads and some coniferous trees. Overlying these deposits are shales and sandstones with marine fossils, as well as plant remains, and these appear to represent the zones of *Psiloceras planorbe* and *Coroniceras Bucklandi*. In Central Scania to the north-east the Rhætic Beds have disappeared, and the marine shales are represented by massive sandstones which lie directly on the Archæan rocks and are made up of detritus derived from the latter.

3. The Alpine Region

In this region and in the south of Europe generally the Lias assumes a completely different facies from that which prevails in Germany and the north of France, for it passes into a series of

massive limestones of which the thickness often amounts to several thousand feet. They indicate, in fact, a continuance of the pelagic conditions which prevailed in the same region during Triassic times.

In the Western Alps Haug has described the Lias as forming three distinct bands round the core of the Cottian Alps; the innermost consisting of crystalline limestones, often brecciated and containing large blocks of the older rocks, but frequently fossiliferous and characterised by a fauna of Corals, Lamellibranchs, and Gastropoda; the second formed of compact limestones (never crystalline), characterised by the abundance of Ammonites; and thirdly, bedded limestones with Crinoids and many Brachiopoda. He regards these three facies as replacive, one outside the other, probably formed in zones of increasing depth of water.

The outer belt is well developed round Digne and in the Basses Alpes, where all the French divisions can be recognised, and the several thicknesses are as below given:

	Feet.
Toarcian (<i>bifrons</i> and <i>radians</i> zones)	660
Charmouthian (limestones and marls)	860
Sinemurian limestones	200
Hettangian (180) and Rhætian (120)	300
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In the Tyrol and Eastern Alps the Lias is represented by red and variegated limestones and spotted marls (*Fleckenmergel*), all of which abound in Cephalopoda. The Rhætic zone of *Pteria contorta* here forms a link between the Trias and the Lias, being in some localities a part of the great Dachstein limestone, but the typical Kössen Beds are marls containing *P. contorta* and black limestones with many Brachiopoda. In the Adneth and Salzburg district the highest member of the Rhætic is a limestone full of the coral *Calamophyllia* (= *Lithodendron*), and this is overlain by variegated limestones containing many Ammonites of the genera *Arietites*, *Phylloceras*, and *Lytoceras* which must represent the Hettangian and Sinemurian stages.

In the Bavarian Alps the Middle Lias is represented by variegated marls with *Amaltheus margaritatus*, but elsewhere it does not seem to be specially distinguishable in the mass of limestones and marls.

The Upper Lias (or Toarcian) is more clearly definable, its equivalent in the Bavarian Alps being red and grey limestones with *Hildoceras bifrons*, and in the Tatra district near Vienna by *fleckenmergel* with the same fossil.

Farther east the whole formation passes into a littoral facies of

sandstones, marls, and shales, with occasional coal-seams, and this extends through Hungary to the Carpathian Mountains. It is evident, therefore, that the sea shallowed rapidly to the east as well as to the north.

Beyond this in Russia no representative of the Lias is known, the lowest beds of the Jurassic System in Central Russia belonging to the Cornbrash or the Callovian. Liassic deposits, however, are found again to the south-east in Servia, Croatia, and Dalmatia, and again in the Caucasus, while littoral beds with plant remains (possibly of Liassic age) have been found at Isjoun on the Donetz in South Russia.

II. MIDDLE JURASSIC SERIES

A. STAGES AND ZONES

This series has always been divided into two stages; a lower, known as the Inferior Oolite Group in England and the *Bajocian* in France, and an upper, best called the Bath Oolite Group and in France the *Bathonian*. The precise limits of these stages have, however, been matters of dispute, and are not yet settled. As stated on p. 387, the most convenient horizon at which to draw the line between the Lower and the Middle Series seems to be at the base of the *opalinum* zone. This places the base of the Inferior Oolite at an horizon which can easily be followed all across England, and it is at this horizon also that the base of the series is taken on the International Geological map of Europe.

With respect to the upper limit of the Bajocian or Inferior Oolite, there is a growing prevalence of opinion that it must be placed at a lower horizon than formerly, and that the zone of *Parkinsonia Parkinsoni* should be included in the Bathonian; for the fauna of this zone is more closely related to that of the beds above it than to that below, and in England there is a marked stratigraphical break at its base. Again, there can be no doubt that whatever line is taken as the plane of separation between the two stages, this line should be drawn at the same horizon both in England and France, so that the stages should be completely correlative.

During the last ten years much detailed zonal work has been done both in England and France, and a large number of zones and sub-zones (or hemeræ) have been proposed. For those who make a special study of this series such work is of much value, but for the general student it will suffice to indicate the broader zones which can be traced over wide areas in England, France, and Germany. These are given in the following table:—

	Zone.
Bath Oolites or Bathonian	<i>Clydoniceras discus.</i> <i>Waldheimia digona.</i> <i>Oppelia fusca</i> and <i>Macrocephalites subcontractus.</i> <i>Parkinsonia Parkinsoni.</i>
Inferior Oolite or Bajocian	<i>Celoceras Blagdeni.</i> <i>Witchellia Ammonites.</i> <i>Lioceras concavum.</i> <i>Ludwigia Murchisonæ.</i> <i>Lioceras opalinum.</i>

B. LIFE OF THE PERIOD

Marine Fauna.—The fauna of the Middle Jurassic rocks is closely related generically to that of the Lias, but differs principally in the relative abundance of Corals, Echinoderms, and Gastropods. This, however, is sufficiently explained by the fact that these limestones were evidently formed in clear water, and sometimes in the neighbourhood of coral reefs. Brachiopoda, too, are individually very abundant, though the number of species is not greater than in the Lias, and the genera are the same, except that *Cadomella* and *Spiriferina* are absent. The following are the more important genera which now appear, and those to which an asterisk is prefixed did not survive the Jurassic period :—

<i>Porifera.</i>	<i>Corynella</i> , <i>Craticularia</i> , <i>Holcospongia</i> , <i>Lymnorea</i> , <i>Peronidella</i> , <i>Verrucocælia</i> .
<i>Anthozoa.</i>	<i>Phyllocænia</i> (= <i>Adelastrea</i>), * <i>Anabacia</i> , <i>Cryptocænia</i> , <i>Cyathophora</i> , <i>Stylina</i> .
<i>Echinoderma.</i>	<i>Apiocrinus</i> , * <i>Clypeus</i> , <i>Collyrites</i> , <i>Nucleolites</i> , <i>Hemici-</i> <i>daris</i> , <i>Holcotypus</i> , * <i>Hyboclypeus</i> , <i>Pedina</i> , <i>Pygaster</i> , <i>Pygurus</i> , <i>Stomechinus</i> .
<i>Brachiopoda.</i>	<i>Terebratulina</i> .
<i>Lamellibranchia.</i>	<i>Corbis</i> , <i>Corbicella</i> , <i>Cyprina</i> , <i>Isocardia</i> , * <i>Pachyrisma</i> , <i>Pteroperna</i> , <i>Sowerbya</i> , <i>Spondylus</i> , * <i>Trichites</i> .
<i>Gastropoda.</i>	<i>Brachytrema</i> , <i>Bulla</i> , * <i>Cirrus</i> , <i>Dephinula</i> , <i>Fissurella</i> , <i>Nerinea</i> , <i>Pileolus</i> , * <i>Purpuroidea</i> , <i>Rissoina</i> .
<i>Cephalopoda.</i>	The Ammonite genera <i>Cosmoceras</i> , * <i>Haploceras</i> , <i>Lioceras</i> , <i>Ludwigia</i> , <i>Macrocephalites</i> , <i>Oppelia</i> , * <i>Parkinsonia</i> , <i>Perisphinctes</i> , <i>Sonninia</i> , and <i>Sphæro-</i> <i>ceras</i> .
<i>Pisces.</i>	<i>Aspidorhynchus</i> , <i>Microdon</i> , <i>Strophodus</i> , <i>Ganodus</i> , <i>Ischyodus</i> .
<i>Reptilia.</i>	<i>Streptospondylus</i> , <i>Teleosaurus</i> .

The following are lists of the fossils which may be regarded as specially characteristic of the groups indicated :—

Fossils of the Bajocian (Inferior Oolite)

<i>Actinozoa.</i>	<i>Anabacia hemispherica</i> , <i>Thecosmilia gregaria</i> .
<i>Echinoderma.</i>	<i>Stomechinus germinans</i> , <i>Pygaster semisulcatus</i> , <i>Hybo-</i> <i>clypeus agariciformis</i> .

- Brachiopoda.* Rhynchonella (Acanthothyris) spinosa, Terebratula fimbria, T. maxillata, T. perovalis, T. Phillipsii, Waldheimia (Aulacothyris) carinata.
- Lamellibranchia.* Astarte elegans, A. excavata, Ceromya bajociana, Gresslya abducta, Gryphæa sublobata, Pholadomya fidicula, Trigonia costata, T. denticulata, T. hemispherica.
- Gastropoda.* Cirrus nodosus, Nerinea cingenda, Pleurotomaria ornata, Pseudomelania procera, Bourguetia striata.

Fig. 133.—GROUP OF INFERIOR OOLITE FOSSILS.

- a. Parkinsonia Parkinsoni. d. Trigonia costata.
 b. Stepheoceras Humphriesianum. e. Pholadomya fidicula.
 c. Nautilus sinuatus. f. Rhynchonella spinosa.
 g. Terebratula perovalis.

Cephalopoda. (For Ammonites see *ante*, p. 410) also Stepheoceras Humphriesianum, Sonninia Sowerbyi, Nautilus truncatus, N. sinuatus.

Fossils of the Great Oolite and Forest Marble

- Actinozoa.* Anabacia complanata, Isastrea explanatula, Apio-crinus Parkinsoni.
- Echinoderma.* Acrosalenia hemicidaroides (ranges to Cornbrash), Hemicidaris minor, Clypeus Ploti, Collyrites ringens.

- Brachiopoda.* Rhynchonella concinna, R. obsoleta, Terebratula maxillata, T. (Dietyothyris) coarctata, Waldheimia digona.
- Lamellibranchia.* Pteria (Oxytoma) costata, Lucina bellona, Lima cardiiformis, Grammatodon hirsonensis, Ostrea acuminata, O. Sowerbyi, Pachyrisma grande, Trigonion Goldfussi, T. Moretoni.
- Gastropoda.* Dicroloma (Alaria) armatum, Amberleya nodosa, Cyllindrites acutus, Purpuroidea Morrisi, Nerinea Voltzi, Patella rugosa, Nerita costulata.

Fig. 134.—GROUP OF BATHONIAN FOSSILS.

a. Pterophyllum comptum.	e. Lima cardiiformis.
b. Hemicidaris minor.	f. Trigonion Goldfussi.
c. Rhynchonella concinna.	g. Purpuroidea Morrisi.
d. Waldheimia digona.	h. Nerinea Voltzi.

- Cephalopoda.* Parkinsonia Parkinsoni, Zigzagiceras arbustigerum, Macrocephalites subcontractum, Oppelia fusca, Nautilus Baberi.
- Pisces.* Strophodus magnus, Pholidophorus minor.
- Reptilia.* Steneosaurus brevidens, Cimoliosaurus erraticus.

Fossils of the Cornbrash

- Actinozoa.* Anabacia complanata.
- Echinoderma.* Holoctypus depressus, Nucleolites clunicularis.

Fig. 135.—GROUP OF CORNBRASH FOSSILS (WITH APIOCRINUS FROM THE BRADFORD CLAY).

- a. *Acrosalenia hemlicidaroides*.
- b. *Apiocrinus Parkinsoni*.
- c. *Terebratula intermedia*.
- d. *Gresslya peregrina*.
- e. *Pleuromya decurtata*.

- f. *Pholadomya lyrata*.
- g. *Clydoniceras discus*.
- h. *Macrocephalites macrocephalus*.
- i. *Nucleolites clunicularis*.
- k. *Ostrea flabelloides*.

- Brachiopoda.* Terebratula intermedia, T. Bentleyi, Waldheimia obovata.
Lamellibranchia. Pseudomonotis echinata, Pecten vagans, Lima duplicata, Pleuromya decurtata, Gresslya peregrina, Pholadomya lyrata, Ostrea flabelloides.
Gastropoda. Pseudomelania vittata.
Cephalopoda. Clydoniceras discus, Macrocephalites macrocephalus.

Fig. 136.—RESTORED SKELETON OF MEGALOSAURUS BUCKLANDI ($\frac{1}{80}$).
 Actual length supposed to be about 30 feet.

Terrestrial and Freshwater Fauna.—The estuarine beds which occur occasionally in these rocks furnish us with some interesting remains of the plants and land animals. The borders

Fig. 137.—JAWS OF (1) PHASCOLOTHERIUM BUCKLANDI AND (2) AMPHITHERIUM BRODERIPI, FROM STONESFIELD.

Natural size, with enlarged views of teeth above.

of the rivers and estuaries must have been clothed with a dense vegetation, ferns of the genera *Matonidium*, *Lacopteris*, *Coniopteris*, *Cladophlebis*, *Todites*, *Sphenopteris*, *Teniopteris*; cycads of many genera, *Williamsonia*, *Ctenis*, *Nilssonia*, *Anomozamites*, *Otozamites*, etc.; coniferous trees, such as *Araucarites*, *Brachyphyllum*, *Baiera*,

and *Ginkgo*. Among this vegetation insects abounded, such as beetles, flies, and dragon-flies.

In the water lived molluscs of the genera *Cyrena*, *Anodonta*, crocodiles of the Gavial type, and turtles (*Protochelys*).

On land there were small marsupials, *Amphitherium*, *Amphitylus*, *Amphilestes*, and *Phascolotherium* (Fig. 137), and the Protothere *Stereognathus*. The huge Dinosauria, *Megalosaurus* and *Ceteosaurus*, were also terrestrial creatures (see Fig. 136).

C. THE MIDDLE JURASSIC OF ENGLAND

Geographical Range.—Like the Lias, the Middle Jurassic Series ranges completely across England from Dorset to Yorkshire. It occupies the Dorset coast between Bridport and Weymouth, and runs inland by Yeovil, Sherborne, and Bruton to the Mendips. In Gloucestershire it gives rise to the well-known scenery of the Cotswolds, and spreads over a considerable width of country. Thence it passes through the counties of Oxford, Northampton, Rutland, and Lincoln, forming the long escarpment known as the "cliff" in Lincolnshire, which runs due north from Grantham by Ancaster, Navenby, Lincoln, and Kirton to the Humber.

In South Yorkshire it makes but little show, the beds being thin, but north-west of Malton they thicken, and, sweeping round to the north of Helmsley, form the high ground of the Yorkshire Wolds, which range from west to east and terminate in the cliffs between Whitby and Scarborough.

The component members of this series in England are a variable series of oolites, shelly limestones, ironstones, clays, and sands; none of the strata continuing long of the same thickness, and many of them thinning out altogether within comparatively short distances. The most persistent stratum is that which forms the summit of the series and is known as the Cornbrash. In the south of England, where the most complete succession of purely marine deposits is found, the series has been divided into the following groups and zones:—

		Zones.
Bath Oolites (Bathonian)	Cornbrash	<i>Clydoniceras discus</i> .
	Forest Marble	<i>Waldheimia digona</i> .
	Great Oolite	<i>Cœloceras subcontractum</i> .
	Fuller's Earth	
Inferior Oolite (Bajocian)	Clypeus and Trigonia grits	<i>Parkinsonia Parkinsoni</i> .
	Terebratula Beds	<i>Wüchellia</i> .
	Gryphite and Trigonia grits	<i>Lioceras concavum</i> .
	Freestones and Pea-grit	<i>Ludwigia Murchisonæ</i> .
	Opalinum band	<i>Lioceras opalinum</i> .

The stratigraphical variations of this series will be best explained by taking first the Bajocian and following it across England from south to north, and then doing the same for the Bathonian. A tabular correlation will be found on p. 427.

Inferior Oolite or Bajocian

Southern Counties.—In Dorset the limestones of this stage are thin, and the lowest zone, that of *Lioceras opalinum*, is represented partly by sand and sandstone, the beds being about 11 feet thick at Chideock, near Bridport, and 5 feet at Burton Bradstock (see Fig. 130). The overlying zones are brown, ironshot limestones, which at Chideock are about 8 feet thick, but at Burton they are barely 3 feet.¹² Farther north, however, near Beaminster, the *opalinum* zone is about 16 feet and the limestones above about 5 feet, making a total of 21 feet; but the uppermost zonal horizon is not everywhere the same, and the surface of the uppermost bed, whatever it may be, is always eroded, either planed off and coated with oysters or worn into irregular hollows.

Between Yeovil and Sherborne the limestones properly belonging to the Inferior Oolite are again very thin, though well exposed in numerous quarries, and the succession given by Mr. Buckman is:—

	Feet.
Limestone with <i>Stepheoceras Humphriesianum</i>	1 to 5
„ <i>Lioceras concavum</i>	3 to 4
„ <i>Ludwigia Murchisonæ</i>	1 to 5
Sandy stone with <i>Lioceras opalinum</i>	1 to 2

About 10

In the Mendip district by Bruton, Doultling, and Frome the Inferior Oolite is entirely absent, having apparently been raised into a broad, low anticline, the upper part of which was eroded and destroyed in the interval between the Bajocian and Bathonian epochs, so that the beds of the latter rest directly and unconformably on those of the Upper Lias or Toarcian.

North of the Mendip ridge the lower beds of the Inferior Oolite come in again with a pisolitic limestone at the base, succeeded by oolitic freestones and ragstones of much greater thickness than in Dorset or Somerset. The following is a generalised table of the succession found in the Bath and Cotteswold areas:—¹³

Names of Beds.	Zones.	Thickness.
Terebratula Beds and Witchellia Grit	} <i>Witchellia</i> . . .	36 to 55
Notgrove freestone		
Gryphite Grit	} <i>Lioceras concavum</i> . . .	20 to 35
Lower Trigonina Grit		
Freestones and Oolitic marl	} <i>Ludwigia Murchisoni</i> . . .	40 to 160
Pea-grit and brown limestone		
Cap of Cephalopoda Bed	<i>Lioceras opalinum</i> . . .	1 to 2
		From 100 to 250

The Cephalopoda Bed was described on p. 399 as a condensed representative of several zones and forming a "junction bed" between the Toarcian and Bajocian of the Cotteswold district.

Above it there are generally some beds of brown ferruginous limestone, and then comes the "Pea-grit," a coarse pisolitic limestone, 4 to 20 feet thick, which extends from Dursley to Nottingham Hill near Winchcombe, a distance of about 30 miles.

The freestones are soft pale-coloured oolites in thick beds, and are locally separable into lower and upper freestones by a band of yellowish oolitic marl full of *Terebratula fimbria*.

The beds which form the zone of *Lioceras concavum* are locally called "grits," but this is a misnomer as they are really rough shelly limestones. The Trigonina Grit is characterised by *Trig. costata*, *T. striata*, and *T. sculpta*, and the Gryphite Grit by *Gryphæa sublobata*. Other common fossils in these beds are *Astarte elegans*, *A. excavata*, *Ceromya bajociana*, and *Pholadomya fidicula*.

The Notgrove freestone occurs only in the northern part of the Cotteswold area, thickening northward from 4 to about 30 feet. It and the overlying beds are grouped together by Mr. Buckman, who regards them as occupying a lower horizon than the zone of *Stepheoceras Humphriesianum*, which appears to be absent in the Cotteswolds.

Above the beds containing *Terebratula Phillipsi* there is a marked plane of erosion, the succeeding "Upper Trigonina Grit," or Parkinsoni zone, cutting across all the beds in several directions, but especially eastwards, till it lies directly on the Lias. In the northern part of the Cotteswold area, between the Vale of Winchcombe and Stow-in-the-Wold, the Inferior Oolite has been flexed into a syncline, while the Vale of Moreton to the east coincides with an anticline, the axes of these flexures running approximately north and south.

These flexures were produced and a plane of erosion cut across them before the deposition of the Bath Oolites, as shown in Fig. 141 which is modified from one drawn by Mr. Buckman.

Midland Counties.—In passing from Gloucestershire into

Fig. 138.—DIAGRAMMATIC VIEW OF THE STRATIGRAPHY OF THE INFERIOR OOLITE IN DORSET, SOMERSET, AND GLOUCESTERSHIRE (after H. B. Woodward).
Distance about 90 miles. Vertical scale about 200 feet to an inch.

5. Bathonian.
- 4b. Freestones, Inferior Oolite.
- 4a. Pea-grit.
3. Yeovil and Cotteswold sands.
2. Upper Lias clays.
1. Paleozoic rocks.

Fig. 139.—SECTION THROUGH THE LIAS AND OOLITES NEAR LINCOLN (by W. D. Carr). Distance about 5 miles.

9. Oxford clay.
8. Cornbrash.
7. Great Oolite clay.
6. Great Oolite limestone.
5. Upper Estuarine Beds.
4. Lincolnshire limestone and Northampton ironstone.
3. Upper Lias.
2. Middle Lias.
1. Lower Lias.

Oxfordshire the Inferior Oolite undergoes a great change. South of Oxford, as above stated, there is no Inferior Oolite, its beds having been destroyed; and near Fawler the base of the Bathonian contains small blocks of the older limestones covered with *Plicatulæ* and pierced by lithodomous molluscs. These conditions continue to and beyond Charlbury, but north-west of that place near Chipping Norton the Bathonian rests on a representative of the *opalinum* zone, consisting of a sandy limestone about 6 feet thick in which *Lioceras opalinum*, *Rhynch. cynocephala*, and other fossils occur; moreover this has a pebbly basement bed resting on the Upper Lias clay.

This sandy limestone may be regarded as the beginning of the Northampton sandstone, which is found again to the eastward at Steeple Ashton and Worton near Deddington, where it consists of calcareous flagstones and sands with ironstone nodules, the beds being 15 or 16 feet thick.

East of the Cherwell valley we enter Northampton; where the whole Inferior Oolite passes into an arenaceous facies with very little limestone of any kind, though with a valuable oolitic ironstone at the base. The lower beds are marine deposits and appear to represent the *opalinum* and *Murchisonæ* zones, but the higher beds are of estuarine origin. Near Northampton the succession is:—

		Feet.
Lower Estuarine	White sands, including a bed with plant remains .	12 to 30
	Yellow sandstone and brown sandy limestone or ragstone, a variable set of beds, sometimes replaced by white sand as at Spratton	10 to 30
Ironstone Beds	Brown ferruginous sandstone and ironstone, with <i>Lioceras opalinum</i> , <i>Astarte elegans</i> , <i>Rhynch.</i> <i>cynocephala</i> , etc.	30 to 40

Average 60 feet

These beds continue to be the sole representatives of the Inferior Oolite till we reach the valley of the Welland, where the thin end of a lenticular mass of limestone appears above the Lower Estuarine Beds and rapidly thickens northward, becoming the important formation known as the Lincolnshire limestone, which in South Lincs is not less than 150 feet thick.

At its base in South Lincolnshire are some beds of fissile sandy limestone, which form a passage from the Lower Estuarine Beds; these contain ferns (*Laccopteris polypodioides*), with *Lucina Wrightii*, *Gervillia acuta*, *Trigonia compta*, *Tr. impressa*, *Astarte elegans*, and *Malaptera Bentleyi*, but no Ammonites. At Collyweston (near Stamford) these beds are 12 feet thick, but they thin northward and are hardly distinguishable at Ancaster.

The Lincolnshire limestone frequently contains beds in which corals are very abundant, and which have evidently been accumulated in the neighbourhood of coral reefs. The upper layers, too, invariably exhibit much current bedding, indicating shallow water conditions. Ammonites are rare, but Echinoderms are not uncommon. Gastropods (*Natica*, *Nerinea*, *Patella*, *Pleurotomaria*, *Trochus*, *Trochotoma*) are common. *Rhynchonellæ* and Lamellibranchs of many species are abundant. The fauna has eminently a shallow-water and coral-reef facies. This limestone appears to represent the higher part of the Inferior Oolite of the Cheltenham district from the Lower Trigonía Grit upward, for the Ammonites quoted from it include *Cæloceras Blagdeni*, *C. sub-radiatum*, *Stepheoceras* cf. *Humphriesianum*, and *Oppelia Truelli*, all characteristic of the higher zones. Mr. Hudleston also considered its Gastropod fauna to indicate the same part of the stage.

In North Lincolnshire the limestone diminishes to about 60 feet, and in South Yorkshire the lower part is represented by shaly limestones and the upper part by oolitic limestones, each set being about 30 feet thick.

Yorkshire.—When they again emerge in North Yorkshire the series has undergone much transformation, and the mass of the Inferior Oolite consists of estuarine sandstones and shales.¹⁴ Marine beds, however, occur at the top and bottom, and also as a thin zone in the midst of the Estuarine Series, the succession being as follows, and the thicknesses those in the cliff sections:—

	Feet.
5. Scarborough limestone	20 to 90
4. Middle Estuarine Beds	50 to 100
3. Millepore Beds (marine)	20 to 40
2. Lower Estuarine Beds	200 to 280
1. The "Dogger" sands and sandstone	30 to 36

Average about 400

1. Above the Liassic shales are yellow and grey micaceous sands containing *Grammoceras aalensis*, *Lingula Beani*, *Rhynchonella cynocephala*. They are surmounted by a sandy oolitic ironstone, which contains many fossils—*Ludwigia Murchisonæ*, *Terebratula trilineata*, and *Nerinea cingenda*; these sands and sandstone may be regarded as the equivalent of the Northampton sands.

2. The Lower Estuarine Series is exposed in the cliffs from Robin Hood's Bay to Huntcliff (see Fig. 140). The shales and oolitic ironstones contain plant remains in some abundance. In the midst of this series is a band of flaggy sandstone and ironstone with marine fossils known as the Eller Beck Bed. It yields *Gervillia acuta*, *Astarte minima*, *Pholadomya Heraulti*, and other fossils.

Showing the succession of beds which represent the Inferior Oolite, Upper Lias, Middle Lias, and part of the Lower Lias. The dotted portions represent glacial deposits (mainly boulder-clay).

3. The Millepore Beds consist of a hard calcareous sandstone with the Bryozoan *Haploecia straminea*, overlain by shales and sandstones containing *Trigonia reticosta*, *Ceromya bajociana*, *Gervillia lata*, *Pygaster semisulcatus*, and other fossils.

4. The Middle Estuarine Series consists of shales and sandstones, with thin layers of coal varying from 2 to 18 inches in thickness. The "plant bed" of Gristhorpe Bay has yielded fine specimens of ferns (*Cladophlebis*, *Sphenopteris*, *Tæniopteris*, etc.), the cycads *Nilssonia* and *Otozamites*, and the horsetail *Equisetites columnaris*.

5. The beds termed the Scarborough limestone are grey, shaly limestones, often ferruginous; they contain *Stepheoceras Humphriesianum*, *Gervillia acuta*, *Pseudomonotis braamburiensis*, etc. They form a lenticular mass, very thin at Gristhorpe, but thickening to the north-west.

The Bath Oolites or Bathonian

Southern Counties.—In Dorset and Somerset this stage consists of four distinct members, viz. :—

	Feet.
4. The Cornbrash, rubbly limestones . . .	15 to 25
3. The Forest Marble, flaggy limestones . . .	80 to 130
2. The Fuller's Earth, chiefly marly clays . . .	150 to 80
1. Earthy, oolitic, and shelly limestones . . .	6 to 45

Average about 250

No. 1 is the zone of *Park. Parkinsoni*, and in South Dorset (at Chideock, Burton, Bradstock, and Beaminster) it is only 6 or 7 feet thick. Near Crewkerne, however, it has thickened to 12 or 15 feet, and near Sherborne the beds vary from 20 to 40 feet. Still farther north at Bruton and Doulting massive beds of oolitic freestone come in, thickening toward the Mendips in contrast to the thinning out of the Inferior Oolite. These beds are quarried for building stone at Doulting, where the following sequence is found below the Fuller's Earth :—

	Feet.
Rubbly and oolitic limestones	10
Doulting stone, quarried as a freestone	44
"Conglomerate Bed," resting on the Upper Liassic clays	1½

A little farther north in Vallis Vale these beds rest directly on Carboniferous limestone. The basal limestone-conglomerate is correlated by Mr. Buckman with the Upper *Trigonia* Grit of the Cotteswolds, and the Doulting Beds with the *Clypeus* Grit. Between them is a break which is filled elsewhere by the "Dundry

FIG. 141.—DIAGRAM SECTION ACROSS THE NORTH COTSWOLD HILLS (after S. S. Buckman). Distance 18 miles.
Showing the unconformity of the Bathonian to the Bajocian (Inferior Oolite).

Bathonian.	{	10. Great Oolite.	7. Terebratula Beds.	4. Clay, tilestone, and sand.
	{	9. Fuller's Earth and Clypeus Grit.	6. Notgrove Freestone.	3. Oolite Marl and Pen-grit.
	{	8. Upper Trigonia Grit.	5. Ragstones and Lower T. Grit.	2. Upper and Middle Lias.

freestone" (an oolite from 4 to 27 feet thick) and a coral bed occurring at Dundry, Midford, and Stroud (6 to 8 feet).

The Fuller's Earth which succeeds the above is a marly clay, generally of a greenish or yellowish grey, but sometimes blue, and some of its beds consist of the fine soft greasy clay which is used for fulling purposes. It also includes a band of earthy limestone which is known as the Fuller's Earth Rock. This rock is thickest in Somerset, where it is often from 25 to 30 feet thick. Its characteristic Ammonite is *Cœloceras subcontractum*, and other common fossils are *Ostrea acuminata*, *Rhynchonella varians*, and *Waldheimia ornithocephala*.

No limestone comparable to the Great Oolite is found in Dorset or Somerset, so that it must either be represented by the upper part of the Fuller's Earth or strong current must have prevented the accumulation of any sediment for a time.

The Forest Marble consists of shelly and flaggy limestones, which show much oblique current bedding and alternate with bands and layers of shaly clay or marl. It was formerly supposed to be over 400 feet thick, but Mr. Woodward has found this to be a mistake; ¹⁵ on the coast near Bridport it is only about 80 feet thick, and its greatest thickness is not in Dorset but in Somerset, near Sherborne, where it is about 130 feet. The limestones have been quarried at many places for building and paving stones.

The Cornbrash in Dorset and Somerset is from 15 to 25 feet thick, and consists of rubbly ferruginous limestone of a bluish-grey colour in its deeper parts, but weathering into a brown rock by oxidation of the iron, and forming a fertile soil (for fossils see p. 417).

In Gloucestershire the *Parkinsoni* zone has been divided into two sub-zones or hemeræas Mr. Buckman calls them: (a) the Upper Trigonia Grit or *garantianæ* hemera, consisting of hard earthy and shelly limestones with *Trigonia angulata*, *T. costata*, and *Rhynch. spinosa*; (b) the Clypeus Grit or *Truelli* hemera, comprising marly oolites with *Clypeus Ploti*, *Nerinea Guisei*, and *Terebratulula globata*. The combined thickness of these beds is about 20 feet near Stroud, but 40 feet on Cleve Cloud near Cheltenham.

The unconformity of the Upper Trigonia Grit and the manner in which its base passes across the outcrops of the underlying beds has been described on p. 421, and illustrated by Fig. 141.

The Fuller's Earth is traceable through the district, but thins northward. Near Stroud it is about 70 feet thick, but not more than 50 near Chedworth, where it passes up into the beds which are known as the Stonesfield slate; these are shales and laminated micaceous sandstones, which are thin in Gloucestershire but become

of more importance in Oxfordshire. Near Bourton the beds are not more than 30 feet thick.

The Great Oolite limestone first sets in near Bradford-on-Avon, and rapidly thickens northward till, near Bath and Minchinhampton, it is from 80 to 100 feet, and includes the well-known freestone which goes by the name of "Bath Oolite." This freestone is from 10 to 30 feet thick, and occurs between two bands of shelly and oolitic limestone, each from 20 to 40 feet thick.

The Forest Marble succeeds, and near Bradford and Bath its basement bed is a band of bluish-grey clay, which is known as the Bradford clay, but is never more than 10 feet thick. It contains many fossils in a fine state of preservation, and has long been known for the abundance of *Apiocrinus Parkinsoni* (the pear Encrinite). It also contains *Waldheimia digona*, *Terebratula coarctata*, and other fossils which are characteristic of the overlying Forest Marble Beds. The latter are from 60 to 100 feet thick, and consist of alternating limestones and clays.

The Cornbrash forms a persistent band at the top of the series, but is never more than 15 feet thick.

Midland Counties.—In Oxfordshire the Bathonian has the following composition :—

	Feet.
Cornbrash and Forest Marble	30 to 35
Great Oolite limestone	40 to 50
Stonesfield Beds and Fuller's Earth	15 to 18
Chipping Norton limestone	12 to 15
Clypeus and Trigonia Grits	12 to 20

The limestones of the *Parkinsoni* zone do not extend into Bucks, but seem to be cut by the base of the Upper Estuarine Beds, *i.e.* by the current action which preceded the deposition of those beds presently to be mentioned.

The Stonesfield Beds into which the Fuller's Earth seems to have passed consist of sandy clays and flaggy sandstones which have yielded a remarkable assemblage of fossils, including the remains of five genera of small mammals—two Pterodactyles, three Crocodiles, the Dinosaur *Megalosaurus*, and the Turtle *Protochelys*, with a large number of fish and of Mollusca. Among the latter are *Nerita costulata*, *Trigonia impressa*, *Gervillia acuta*, *Modiola imbricata*, with *Rhynchonella concinna*. Besides these are remains of ferns, cycads, and conifers.

When traced northwards into Northampton the Stonesfield Beds pass into a set of sands and clays which are called the Upper Estuarine Series. In the absence of the Inferior Oolite limestone these beds rest on the estuarine beds of the Northampton Group,

but the two estuarine groups are sharply divided from one another, the base of the upper group being a layer of ironstone nodules which rests on an eroded surface of the lower sands. The fossils are chiefly marine species, such as *Ostrea Sowerbyi*, *Modiola imbricata*, *Perna rugosa*, and *Pteroperna plana*, but *Cyrena* and plant remains sometimes occur.

The Great Oolite consists of hard limestones alternating with marly clays. These beds contain *Gervillia Waltoni*, *Astarte angulata*, *Terebratula maxillata*, *Rhynchonella concinna*, and many other fossils, and near Fairford is a white limestone which has yielded many corals, such as *Isastrea explanatula*, *I. limitata*, and *Thamnastrea Lyelli*.

The Forest Marble derives its name from Wychwood Forest near Burford in Oxfordshire, where it has been largely quarried. It is continued into Buckinghamshire, but near Buckingham the limestones thin out, leaving only the clays to represent this member of the series; these form a band which is known as the Great Oolite Clay, but it is only from 10 to 20 feet thick.

In consequence of the changes above mentioned the stage presents quite a different facies in Rutland and Lincoln, where it is less than 100 feet thick and consists of four members which are persistent through both these countries. These are:—

	Feet.
4. The Cornbrash	about 15
3. The Great Oolite Clays	20
2. The Great Oolite limestone	20
1. The Upper Estuarine Beds	30

The Upper Estuarine Beds consist of white, blue, green, and variegated clays, with seams of lignite and occasional courses of sandy stone; the basement bed is a brown ferruginous nodular sandstone, which rests unconformably upon the Lincolnshire limestone in Rutland and Northampton, though in Lincolnshire no such evidence of erosion has been observed. The fossils are sometimes marine, sometimes estuarine forms (*Cyrena*, etc.).

The Great Oolite Limestone consists of soft, white, marly limestones, separated by layers of marly clay. The prevalent fossils are *Ostrea Sowerbyi*, *O. subrugulosa*, *Homomya gibbosa*, and *Clypeus Mulleri*.

The Great Oolite Clays are of many colours—blue, green, yellow, and purple; the only fossils are *Placunopsis socialis* and the oysters above mentioned.

The Cornbrash is as usual full of fossils; *Holctypus depressus*, *Nucleolites clunicularis*, *Pseudomonotis echinata*, and *Macrocephalites macrocephalus* are characteristic and common.

CORRELATION TABLE OF THE MIDDLE JURASSIC SERIES

Dorset and Somerset.	Gloucestershire.	Oxfordshire.	Rutland and Lincolnshire.	Yorkshire.	Scotland.
<p>Cornbrash</p> <p>Forest Marble</p> <p>Absent</p> <p>Fuller's Earth</p>	<p>Cornbrash</p> <p>Forest Marble</p> <p>Great Oolite</p> <p>{ Stonesfield slate and Fuller's Earth</p>	<p>Cornbrash</p> <p>Forest Marble</p> <p>Great Oolite</p> <p>{ Stonesfield Beds</p>	<p>Cornbrash</p> <p>Great Oolite Clay</p> <p>Great Oolite Limestone</p> <p>Upper Estuarine Beds</p>	<p>Cornbrash</p> <p>Upper Estuarine Beds, 200 feet</p>	<p>Estuarine Series, 850 feet.</p>
<p>Sherborne and Douling Beds</p>	<p>Clypeus and Upper Trigonina Grits</p>	<p>Clypeus and Upper Trigonina Grits</p>	<p>Absent</p>	<p>Marine limestone.</p>	
<p>Limestones, 5 to 10 feet</p>	<p>Limestones of the <i>Witchellia</i> and <i>concaum</i> zones</p> <p>Freestones and Pea-grit</p>	<p>Absent</p> <p>Absent</p>	<p>Lincolnshire Limestone</p> <p>Lower Estuarine Beds</p> <p>Northampton Sand</p>	<p>Scarborough Limestone</p> <p>Middle Estuarine Millepore Beds</p> <p>Lower Estuarine Beds</p> <p>"Dogger"</p>	<p>Sandstones and shales, 220 feet.</p> <p>Cale. sandstones and shales, 120 feet.</p>
<p>Opalinum sands</p>	<p>Opalinum stone</p>	<p>Opalinum stone</p>			

On the Yorkshire coast the whole group is represented by shales and sandstones of estuarine origin, capped by a thin band of Cornbrash.

In Gristhorpe Bay this Upper Estuarine Series is 120 feet thick, consisting of marine sandstones in the lower part and shales with thin sandstones above. Farther north they are over 200 feet thick. A few ferns are the only fossils.

The Cornbrash is very thin, only 5 or 6 feet, but has the usual characters, being a grey rubbly ironshot limestone full of the ordinary fossils, among which are *Macrocephalites Herveyi*, *Pseudomonotis echinata*, *Lima rigidula*, and *Waldheimia lagenalis*.

D. THE MIDDLE JURASSIC IN SCOTLAND

1. West Coast

"Rocks of this age," says Professor Judd,¹⁶ "must have originally had a very wide distribution, for traces of them are found at various points from the Shiant Isles in the north to Ardnamurchan in the south. The best exposures of their strata, however, are those which occur in the islands of Skye and Raasay" (see Fig. 132). Here the Inferior Oolite consists of the following beds:—

	Feet.
Beds of white sandstone with thin shaly bands containing remains of ferns and cycads	60
Beds of sandstone and shale, the former passing into shelly limestones, <i>Steph. Humphriesianum</i> , <i>Belemnites giganteus</i>	160
Sandy micaceous shales alternating with calciferous sandstones, <i>Ludwigia Murchisonæ</i> , <i>Harpoceras corrugatus</i> , <i>Belemnites giganteus</i> , <i>Lucina Wrightii</i> , etc.	120
	<hr/> 340

These beds are succeeded by a great thickness of strata belonging to the Bathonian Group. At the base are marine limestones almost wholly made up of comminuted shells, but containing perfect *Ostrea Sowerbyi*, *Waldheimia lagenalis*, etc. They probably represent the zone of *Parkinsonia Parkinsoni* and are 45 feet thick. Above them are estuarine sandstones and shales fully 500 feet thick but not well exposed.

Farther south, however, in the islands of Eigg and Muck this estuarine group is still thicker and is accessible, the following succession being seen:—

A. The lowest beds are fine conglomerates and shelly limestones full of freshwater shells, but containing also remains of *Plesiosaurus*, turtles, and other reptiles. Above these are black shales and limestones abounding in Cyprids, fish remains, and shells of *Cyrena*,

Cyclas, and *Viviparus*. The thickness of the whole group is 200 feet.

B. Grey and white sandstones, sometimes passing into calcareous grits, with large concretionary siliceous masses; current-bedding and ripple-marked surfaces are frequent, but excepting plant remains fossils are rare. Thickness probably more than 500 feet.

C. The highest beds are black shales with thin bands of argillaceous limestone and bands of fibrous carbonate of lime; they are sometimes crowded with *Cyrena* and *Cyclas*, and in other places with *Viviparus*, *Melania*, and other Gastropoda. Beds entirely composed of oysters (*O. hebridica*) also occur, resembling those in the Purbeck Series (see *postea*). Thickness 150 feet.

2. East Coast

Beds of Middle Jurassic age occupy a small space on the coast of Sutherland south of Brora, and form two small patches at Burgh Head and Stotfield, on the coast of Elgin. They consist entirely of estuarine strata, which are lithologically comparable to those of the Great Oolite Group on the western coast. The descending succession near Brora is as follows:—

	Feet.
"Roof bed," calcareous sandstone (Kellaway)	3½
Coal composed of crushed <i>Equisetites</i>	
Black shales with thin coal-seams in the upper part, plants, and crushed shells of <i>Unio</i> , <i>Ostrea</i> , <i>Cyrena</i> , etc., abound; also teeth and scales of fish, <i>Lepidotus</i> , <i>Pholidophorus</i> , and <i>Hybodus</i>	26
Black, brown, and grey clays with layers of argillaceous limestone, <i>Cyrena</i> and <i>Ostrea</i>	96
White sandstones with some beds of clay; in this a few obscure marine shells occur	110

The base is not seen, and whether any beds comparable to the Inferior Oolite of the west coast exist below is, therefore, unknown.

At Stotfield there are soft greenish-white sandstones containing *Ostrea Sowerbyi*, *Tancredia axiniformis*, and *Astarte hambordalisi*, and are probably near the base of the Bathonian Series.

E. CONTINENTAL EQUIVALENTS

1. France

The Middle Jurassic strata of the Parisian basin are a continuation of the British Series, and their outcrop is almost continuous round the basin, though concealed here and there beneath the transgressive Cretaceous deposits. The districts where the succession is most clearly exposed are that of Bayeux and Caen in

Normandy, the southern border of the Ardennes, and the broad outcrop on the borders of France and Germany, extending southward to the Jura Mountains.

In Normandy the succession is as follows :—

Bathonian, 250 feet.	Marly limestone and blue clay, 12 feet (= Cornbrash).
	Bryozoan limestone with <i>Waldheimia</i> (<i>Zeilleria</i>) <i>digona</i> , <i>Terebratula flabellum</i> , and <i>Eudesia cardium</i> , 30 feet (= F. Marble).
	Compact oolitic limestones with <i>Lucina bellona</i> , 30 to 60 feet (= Great Oolite).
	Caen limestone with <i>Rhynchonella</i> (<i>Acanthothyris</i>) <i>spinosa</i> , passing northward into Bessin limestone with <i>Oppelia fusca</i> , 100 feet (= Fuller's Earth).
	White Oolite with <i>Parkinsonia Parkinsoni</i> , 60 feet.
Bajocian, 15 feet.	Ferruginous Oolites with <i>Cosmoceras subfurcatum</i> and <i>Strenoceras garantianum</i> , 2 feet.
	Brown Oolite with <i>Celoceras Blagdeni</i> , 1 foot.
	Glauconitic limestone with <i>Sphaeroceras</i> , 1 foot.
	White limestone with flints, <i>Ludwigia Murchisonæ</i> , and <i>Lima heteromorpha</i> , 9 feet.
	Limestone with <i>Lioceras opalinum</i> and a layer of phosphatised Ammonites derived from the Toarcian at the base, 2 feet.

On the other side of France, in the French Ardennes and thence eastward into Lorraine, the series presents a different facies with a much thicker development of limestones. The succession there is :—

Bathonian, 400 feet.	Platy limestone with large Oysters (<i>Ostrea flabelloides</i>), 15 feet.
	Marly limestone with <i>Waldheimia digona</i> , <i>Eudesia cardium</i> , and <i>Nucleolites</i> (= <i>Echinobrissus</i>) <i>clunicularis</i> , etc., 100 feet.
	White chalky limestones and oolites, 200 feet.
	Oolite with <i>Clypeus Ploti</i> , 30 feet.
Bajocian, 300 feet.	Yellow sandy limestones with <i>Parkinsonia Parkinsoni</i> and <i>Ostrea acuminata</i> , 60 feet.
	Yellow limestone with <i>Pteria ornata</i> .
	Oolitic limestones and marls with <i>Celoceras Blagdeni</i> .
	Marly limestones with corals, <i>Belemnites giganteus</i> and <i>Sonninia Sowerbyi</i> .
	Thin bed with <i>Lioceras opalinum</i> .

In the French Jura the succession is somewhat similar, but differs somewhat in zonal detail, being as follows :—

Bathonian, 400 feet.	Platy limestones with large oysters, <i>Waldheimia</i> (<i>Zeilleria</i>) <i>digona</i> and <i>Nucleolites clunicularis</i> , 26 to 120 feet.
	Compact white limestones with <i>Rhynchonella decorata</i> , 200 feet (= Great Oolite).
	Marly limestone with <i>Pholadomyas</i> } Fuller's Earth
Bajocian, 140 feet.	Marls of Vesoul with <i>Ostrea acuminata</i> } (130 feet).
	White Oolite with <i>Cosmoceras subfurcatum</i> , 20 feet.
	Marls with <i>Belemnites giganteus</i> .
	Crinoidal limestones with <i>Emeleia polyschides</i> , <i>Witchellia</i> , and <i>Lioceras concavum</i> .
	Ferruginous limestone with <i>Ludwigia Murchisonæ</i> and <i>Lioceras opalinum</i> .

2. Germany

In the south of Germany the outcrop of this series follows that of the Lias from the Black Forest through Swabia and Franconia. In the south-west of this tract, near Tuttlingen and Nusplingen, the facies is calcareous and similar to that of the Northern Jura, but eastward the limestones are largely replaced by clays, and the Bathonian portion becomes much thinner as if approaching a shoreline. In East Swabia the succession is as follows:—

Bathonian, 80 feet.	<ul style="list-style-type: none"> Clays and marls with <i>Rhynchonella varians</i> and <i>Parkinsonia ferruginea</i>, 16 feet. Limestone with <i>Oppelia fusca</i> passing into blue clay, with <i>Parkinsonia Parkinsoni</i>, 10 to 100 feet. Clays and limestones with <i>Cosmoceras subfurcatum</i>, 10 feet.
Bajocian, 350 feet.	<ul style="list-style-type: none"> Zone of <i>Witchellia Romani</i>, limestones with <i>Stepheoceras subconrotatum</i> and clays with <i>Belemnites giganteus</i>. Zone of <i>Sphæroceras Sauzei</i>, blue limestones. Zone of <i>Lioceras concavum</i>, clays and marls. Zone of <i>Ludwigia Murchisonæ</i>, sands, clays and ironstones, 80 feet. Zone of <i>Lioceras opalinum</i>, dark clays, 200 feet.

Apart from the lithological composition of the series the most noteworthy fact is the great expansion of the *opalinum* and *Murchisonæ* zones, as compared with the lesser thickness of the overlying limestones. In Northern Germany there is a similar succession of shales with very little limestone, and the whole series is not more than 100 feet thick. It probably underlies the greater part of the Hanoverian and Prussian plains, and is known to occur in Pomerania; eastward in Silesia the lowest Jurassic Beds belong to the *Parkinsoni* zone; while in Poland near Cracow there are sands and clays of Bajocian age overlain by 100 feet of dark-grey clays with *Parkinsonia wurtembergica* (Bathonian) and succeeded by a ferruginous oolite with *Rhynchonella varians* and *Belemnites bessinus*; but farther east these beds thin out, leaving the Callovian to form the base of the Jurassic System.

3. Alpine and Mediterranean Facies

In the western sub-Alpine region, Savoy and Lower Provence, the Middle Jurassic has a thick and special development, and is over 1000 feet thick. The Bajocian consists of regular alternating beds of marly limestone and shaly marl, characterised by the abundance of Ammonites of the genera *Lytoceras* and *Phylloceras*. The succession of zones is similar to that of the Jura and Swabia, and the same species can be taken as indices, but each zone is also characterised by one or more species of *Phylloceras*, and this is a

special feature of the Mediterranean and Alpine facies. Near Digne the Bajocian is 660 feet thick. In the same region the Bathonian consists mainly of black shales which are divisible into two zones, viz. :—

2. Black marly shales with *Posidonia alpina*, 300 to 400 feet.

1. Black shales and marly limestone with *Oppelia fusca*, 170 feet.

Eastward, however, both stages pass into the condition of marly limestones, and in a more or less metamorphosed form they show themselves at intervals through the Swiss and Italian Alps, and recur in the Apennines. In the Eastern Alps (Klaus Alp) Bathonian shales with *Posidonia alpina* occur, and again near Vienna there is Bajocian with *Phylloceras* and Bathonian with *Posidonia*. These beds extend to the Carpathians, and occur also in Servia, where (near Milanovitz) the Bajocian is absent, and beds with *Oppelia fusca* and *Zigzagiceras arbustigerum* rest directly on crystalline schists.

III. UPPER JURASSIC SERIES

A. SUBDIVISION AND NOMENCLATURE

In England, where fully developed, this series is divisible into five groups or stages—two great argillaceous formations (the Oxford and Kimeridge clays), each overlain by a group of sandstones and limestones (the Corallian and the Portland Beds); while at the summit are the Purbeck Beds, a set of estuarine and lacustrine strata which may be regarded as formed during a continuance of Portlandian conditions in the purely marine areas.

On the continent the thick clays are in many places represented by limestones and marls, so that the British names are not literally applicable; but in Germany and Northern France the general succession is similar, and many of the English names have been employed in a latinised form. In Southern France and the south of Europe generally there is a very different facies, wholly calcareous and marine with a different assemblage of fossils.

The following table shows the nomenclature used in Northern Europe, but the French stages do not exactly correspond with those of England and Germany, as will be shown in the sequel.

England.	North France.	North Germany.
5. Purbeck Beds }		Munder Mergel
4. Portland Beds }	Portlandian	and Plattenkalk.
3. Kimeridge clay	Kimeridgian	Kimeridgian.
2. Corallian Beds	Corallian	Corallian.
1. Oxford clay and Kellaways Beds	{ Oxfordian } { Callovian }	Oxfordian.

B. LIFE OF THE PERIOD

The Upper Jurassic fauna is merely a continuation of that which preceded it, the genera being the same, though the species are for the most part different, only about sixty species passing from the Cornbrash into Oxford Clay.

The most impressive feature of the later fauna is the abundance of reptilian remains. The Jurassic period has been termed the

Fig. 142.—SKELETON OF SCAPHOGNATHUS CRASSIROSTRIS (4) FROM SOLENHOFEN, GERMANY.

“age of reptiles,” and these creatures seemed to have reached the climax of their dominion towards the close of the period. Their numbers and the variety of their modifications are quite extraordinary. Not only did they swarm in the seas and rivers, but they peopled the land with gigantic herbivores and filled the air with winged forms. They thus adapted themselves for all kinds of food and all conditions of life with an elasticity of organisation which is truly remarkable, and to which no parallel can be found in the subsequent history of the world, unless it is among the modern Mammalia, though no member of that class possesses powers of flight comparable to those of the Pterodactyles.

Of Upper Jurassic reptiles, *Cimoliosaurus*, *Peloneustes*, *Pliosaurus*, *Ichthyosaurus*, with the crocodiles *Teleosaurus*, *Steneosaurus*, *Dakosaurus*, and *Goniopholis* were the chief aquatic genera. *Ceteosaurus*, *Gigantosaurus*, *Iguanodon*, *Omosaurus*, and *Cryptosaurus* were terrestrial Dinosaurs, and in America other remarkable genera, *Brontosaurus* and *Atlantosaurus*, both of enormous size, have been found.

Fig. 143.—GROUP OF OXFORDIAN FOSSILS.

a. <i>Gryphæa dilatata</i> .	d. <i>Cosmoceras Jason</i> .
b. <i>Anatina undulata</i> .	e. <i>Cardioceras excavatum</i> .
c. <i>Dicroloma compositum</i> .	f. <i>Belemnites hastatus</i> .
g. <i>Leptolepis macrophthalmus</i> .	

Of Pterosauria species of *Pterodactylus*, *Scaphognathus* (Fig. 142), and *Rhamphorhynchus* were prevalent.

That small Mammalia existed throughout the Jurassic period on terrestrial surfaces there can be little doubt, but their remains are not found in purely marine deposits. The Purbeck Beds, however, have yielded no fewer than twelve genera and twenty species of marsupials, the most important genera being *Plagiaulax*, *Belodon*, *Spalacotherium*, *Triconodon*, *Stylodon*, and *Amblotherium*.

Birds also of a primitive kind had now come into existence,

but the only known genus is *Archæopteryx*, whose remains occur in limestones of Portland age at Solenhofen in Bavaria. This bird had strong reptilian affinities in the structure of its head and tail,

Fig. 144.—GROUP OF CORALLIAN FOSSILS.

a. <i>Thecosmilia annularis</i> .	e. <i>Cerithium muricatum</i> .
b. <i>Acrosalenia decorata</i> .	f. <i>Aspidoceras perarmatum</i> .
c. <i>Goniomya litterata</i> .	g. <i>Belemnites abbreviatus</i> .
d. <i>Trigonia clavellata</i> .	h. <i>Cidaris florigemma</i> .
i. <i>Pholadomya aqualis</i> .	

and in possessing teeth, but it had feathered wings, a feathered tail, and feet adapted for grasping boughs of trees.

Fish were evidently abundant in the seas, their teeth and scales being often found, and sometimes the entire skeleton; the chief genera are *Leptolepis* (Fig. 143), *Aspidorhynchus* (Fig. 147), *Pholidophorus*, *Gyrodus*, *Lepidotus*, and *Hybodius*.

Of Invertebrates very few new genera make their appearance except among the Echinodermata and the Ammonoidea. The Echinoderm genera *Peltastes*, *Acrocidaris*, *Glypticus*, *Magnosia*, and *Cyphosoma* make their appearance. Among the Ammonoids many of Middle Jurassic forms die out, while the following appear: *Aspidoceras*, *Cardioceras*, *Craspedites*, *Holcostephanus*, *Peltoceras*,

Fig. 145.—GROUP OF KIMERIDGIAN FOSSILS.

a. <i>Rhynchonella inconstans</i> .	d. <i>Thracia depressa</i> .
b. <i>Exogyra virgula</i> .	e. <i>Pleurotomaria reticulata</i> .
c. <i>Astarte hartvillensis</i> .	f. <i>Orbiculoidea latissima</i> .
g. <i>Perisphinctes biplex</i> .	

Polyptychites, and *Ancyloceras*. Of Dibranchiate Cephalopoda *Belemnoteuthis* and *Cocconeuthis* are new.

The following are some of the characteristic species of each stage as developed in Northern Europe:—

Fossils of the Oxfordian

Brachiopoda. *Rhynchonella socialis*, *Waldheimia impressa*.

Lamellibranchia. *Gryphæa dilatata*, *Pseudomonotis ovalis*, *Pecten fibrosus*, *Pleuromya recurva*, *Anatina undulata*, *Nucula ornata*, *Trigonia irregularis*.

- Gastropoda.* Dicroloma (Alaria) trifidum, D. compositum, Cerithium muricatum.
- Cephalopoda.* Kepplerites calloviensis, Cosmoceras jason, Cosm. ornatum, Quendstedtoceras Lamberti, Peltoceras athletum, Cardioceras cordatum, Belemnites hastatus, Bel. Oweni.
- Pisces.* Leptolepis macrophthalmus.
- Reptilia.* Cimoliosaurus plicatus, Pliosaurus ferox.

Fossils of the Corallian Group

- Actinozoa.* Thecosmilia annularis, Thamnastrea arachnoides, Th. concinna, Isastrea explanata.

Fig. 146.—GROUP OF PORTLANDIAN FOSSILS.

- a. Pecten lamellosus. c. Lucina portlandica.
b. Trigonía gibbosa. d. Natica elegans (cast).
e. Cerithium portlandicum (cast).

- Echinoderm.* Cidaris florigemma, Hemieidaris intermedia, Acrosalenia decorata, Nucleolites scutatus, Holecypus depressus.
- Brachiopoda.* Terebratula insignis, Waldheimia bucculenta, Rhynchonella Thurmanni.
- Lamellibranchia.* Gervillia avienoides, Pecten articulatus, Ostrea gregaria, Goniomya litterata, Trigonía clavellata, Tr. perlata, Pholadomya æqualis.
- Gastropoda.* Cerithium muricatum, Bourguetia striata, Pseudomelania heddingtonensis, Nerinea Goodhalli, Littorina muricata.
- Cephalopoda.* Aspidoceras perarmatum, Perisphinctes plicatilis, Belemnites abbreviatus.

Fig. 147.—GROUP OF PURBECK FOSSILS.

a. <i>Mantellia nidiformis</i> .	g. <i>Pleurosternon ovatum</i> (carapace).
b. <i>Mantellia microphylla</i> .	h. <i>Goniopholis crassidens</i> (tooth).
c. <i>Ostrea distorta</i> .	i. <i>Cyrena elongata</i> .
d. <i>Physa Bristovi</i> .	k. <i>Bupreston stygnus</i> (elytron).
e. <i>Cyrena media</i> .	l. <i>Archæoniscus Edwardsi</i> .
f. <i>Unio compressus</i> .	m. <i>Aspidorhynchus Fischeri</i> .

Fossils of the Kimeridgian

Brachiopoda. *Orbiculoidea latissima*, *Lingula ovalis*, *Rhynchonella inconstans*.

- Lamellibranchia.* *Ostrea deltoidea*, *Thracia depressa*, *Astarte hartwellensis*,
A. minima, *Diceras arietinum*, *Trigonia monilifera*,
Protoecardia striatula, *Exogyra virgula*.
Gastropoda. *Pleurotomaria reticulata* (also Oxfordian and Corallian),
Littorina pulcherrima, *Harpagodes Oceani*.
Cephalopoda. *Perisphinctes biplex*, *Per. mutabilis*, *Cardioceras*
alternans, *Reineckia endoxus*, *Oppelia tenuilobata*,
Stenoceras calisto, *Belemnites nitidus*.
Reptilia. *Ichthyosaurus trigonus*, *Ich. entheciodon*, *Plesiosaurus*
trochanterius, *Pliosaurus macromerus*, *Geosaurus*
maximus.

Fossils of the Portlandian

- Actinozoa.* *Isastrea oblonga*.
Brachiopoda. *Waldheimia boloniensis*.
Lamellibranchia. *Protoecardia dissimilis*, *Cytherea rugosa*, *Perna myti-*
loides, *Peeten lamellosus*, *Trigonia gibbosa*, *Lucina*
portlandica, *Ostrea expansa*, *Aucella Pallasi*.
Gastropoda. *Cerithium portlandicum*, *Neritoma sinuosa*, *Natica*
elegans, *Pleurotomaria rugata*.
Cephalopoda. *Holcostephanus giganteus*, *Hol. portlandicum*, *Peri-*
sphinctes gigas, *Per. boloniensis*.

Fossils of the Purbeck Beds

(Estuarine, Freshwater, and Terrestrial)

- Plants.* *Sequoia portlandica*, *Cycadeoidea nidiformis*, *C. micro-*
phylla, *Chara Jaccardi*.
Echinoderma. *Hemieidaris purbeckensis*.
Crustacea. *Cypridea purbeckensis*, *Cy. granulosa*, *Cy. punctata*,
Archæoniscus Edwardsi.
Lamellibranchia. *Corbula alata*, *Cyrena media*, *C. elongata*, *Ostrea dis-*
torta, *Unio valdensis*.
Gastropoda. *Physa Bristovi*, *Viviparus carinifera*, *V. elongatus*,
Planorbis Fisheri, *Melanopsis harpæformis*.
Insecta. *Bupreston stygnus* (a beetle), and many others.
Pisces. *Lepidotus minor*, *Hybodus striatus*, *Microdon radiatus*,
Aspidorhynchus Fisheri.
Reptilia. *Goniopholis*, *Theriosuchus*, *Nannosuchus* (Crocodiles),
Chelone and *Pleurosternon* (Turtles), and *Dorato-*
rhynchus (a Pterodactyle).
Mammalia. See *ante*, p. 434.

C. THE UPPER JURASSIC OF BRITAIN

Geographical Range.—The cliffs of the south coast near Weymouth and Portland expose good sections of all these rocks, but the inland outcrop of the Portland and Purbeck Beds is repeatedly concealed by the overstep of the Cretaceous strata. They appear, however, for a space near Tisbury in the Vale of Wardour, and again near Devizes. From Calne and Swindon their outcrop is

more continuous through Oxford, Berkshire, and Buckinghamshire, but the limestones die out in the last county, and only the clays remain through Bedford, Cambridge, Huntingdon, and Lincoln. In South Yorkshire they are entirely concealed by the Cretaceous overstep, but in North Yorkshire there is a fine development of the Oxfordian, Corallian, and Kimeridgian Groups. In Scotland the Oxford Clay exists on the west coast, and the complete series is found on the coast of Sutherland.

With regard to the eastward extension of these rocks beneath the newer systems in the south-east of England we have the testimony of four important borings. The Sub-Wealden boring near Battle traversed all the higher groups, and a large part of the Oxfordian, terminating at a depth of 1905 feet from the surface. In the Dover boring all the members of the series were found to be greatly reduced in thickness, the combined thickness of the Portlandian, Kimeridgian, Corallian, and Oxfordian being only 452 feet. A boring at Chatham proved the existence of Oxford Clay immediately below the Lower Greensand, a fact which makes it probable that there was considerable erosion of the Upper Jurassic Series before the deposition of the Lower Cretaceous sands in that district. There is a similar gap and unconformity at Richmond, where a boring found the Lower Greensand resting directly on Great Oolite. It is probable that the Oxfordian, Corallian, and Kimeridgian Groups originally spread over the area which underlies the Thames valley, but no traces of them have been found in any of the deep borings in Essex, Suffolk, or Norfolk, where Cretaceous rocks everywhere rest directly on a plateau of Palæozoic rocks.

In dealing with the stratigraphy of this series, the simplest plan will be to take each stage separately, and indicate its variations from what may be regarded as its typical development in Dorset as it is followed northwards along the line of outcrop.

1. The Oxford Clay (Oxfordian).—Lithologically this is divisible into two unequal parts (1) the Kellaways Beds, a set of sands and clays with beds of shelly sandstone or sandy limestone; and (2) the Oxford Clay proper, including over 400 feet of bluish clays with occasional layers of earthy limestone. Palæontologically, however, it can be divided into at least three zones,¹⁷ viz. :—

- Zone of *Cardioceras cordatum* —Blue clays with septaria.
- „ *Cosmoceras ornatum* —Grey clays and shales.
- „ *Kepplerites calloviensis* = Kellaways Beds.

Part of the Oxford Clay is well exposed near Weymouth, where the highest zone is about 250 feet, the central beds probably about

200, and the Kellaways about 50 feet. These latter beds take their name from a place called Kellaways near Chippenham in Wiltshire, where they are about 60 feet thick; in that district too the overlying beds are exposed in several places, yielding *Cosm. ornatum*, *Cosm. Elizabethæ*, and *Peltoceras athletum*; while in the higher beds *Gryphæa dilatata* is an abundant fossil.

In the counties of Oxford, Buckingham, Bedford, Huntingdon, and Cambridge the thickness of the stage is about 450 feet, and the same three zones are everywhere traceable. That of *Cosmoceras ornatum* is well exposed in brickyards near Oxford, and that of *Kepplerites calloviensis* in quarries and cuttings near Bedford. Near Huntingdon and Peterborough Professor Judd recognised the following sequence:—

5. Clays with *Card. cordatum* and *Quensted. Lamberti*.
4. Clays with *Cosm. ornatum* and *Duncani*.
3. Clays with *Belemnites hastatus* and *Bel. Oweni*.
2. Shales with *Nucula nuda* and *Cosm. jason*.
1. Kellaways Beds, soft sands and clays.

Near Peterborough the clays of No. 3 have yielded ten species of reptiles and five of fish. In this district also, as well as round St. Neots and St. Ives, the higher beds include bands of limestone as well as septaria, and yield the characteristic Ammonites in great abundance.

The Oxford Clay borders and underlies the western part of the Fen district, emerging on the north side of the river Witham near Bardney, and passing northward to the valley of the Ancholme, which drains into the Humber.

When it emerges from the Cretaceous overlap in Yorkshire the beds have a more variable composition. The Kellaways zone is represented by a massive brownish calcareous sandstone, but where this first appears it is only 9 feet thick; in Gristhorpe Bay it is 24 feet, and at Scarborough, 5 miles to the north-west, there are no less than 76 feet of sandstone. It seems, however, that only the lower 62 feet of this belong properly to the Kellaways, for the highest beds contain *Gryphæa dilatata* and Ammonites of the *Ornatum* Group, which characterise the lower part of the Oxford Clay elsewhere. Above this sandy zone are grey sandy shales 120 feet thick, containing *Quenst. Lamberti*, *Card. cordatum*, *Cosm. crenatum*, and other fossils. Westward both shales and sands decrease in thickness, and are only 80 feet thick in the Howardian Hills.

2. The Corallian Group.—This stage was termed the "Coral Rag" by William Smith in 1815, from the abundance of corals in some of its beds, and it was subsequently divided by J. Phillips into a lower and upper "Calcareous Grit," with the "Coralline

oolite" between them. The name "Corallian" was proposed by d'Orbigny in 1849, and is now generally adopted as more convenient for the variable group of beds which intervene between the Oxford and Kimeridge Clays. Two zones can be recognised, which can also be called the Lower and Upper Corallian, thus:—

Upper	{ Upper rags and grits }	Zone of <i>Perisphinctes plicatilis</i>
Corallian	{ Coral Rag limestones }	
Lower	{ Lower Calcareous Grit, Zone of <i>Aspid. perarmatum</i> .	
Corallian		

In South Dorset the Corallian has a thickness of about 200 feet, but in North Dorset it is not more than 120, and thence northwards it varies from 80 to 100. The component beds are well exposed in the cliffs south of Weymouth, where local names have been given to the several members of the succession by Messrs. Blake and Hudleston,¹⁸ as below:—

		Feet.
Upper Corallian	Sandsfoot Grits	15 to 25
	Sandsfoot Clay	12 to 40
	<i>Trigonia</i> Beds, shelly ragstones	12 to 16
	Osmington oolite, limestones, and marls	40 to 60
Lower Corallian	Benclyff Grits, false-bedded sands	10 to 35
	Nothe Clay, bluish sandy clays	30 to 40
	Nothe Grits, calcareous grits, and marls	20 to 35

The Nothe Grits and Clays contain a mixture of Oxfordian and Corallian species—*Gryphæa dilatata*, *Cardioceras cordatum*, *Ostrea gregaria*, and *Trigonia perlata*. The Osmington and *Trigonia* Beds represent the Coral Rag, but corals are rare; the rags contain *Trigonia clavellata*, *Gervillia aviculoides*, *Nerinæa Goodhalli*, *Am. plicatilis*, and many other fossils. The Sandsfoot Clays and Grits yield *Astarte supracorallina*, with *Thracia depressa*, *Ostrea deltoidea*, *Rhynchonella inconstans*, and *Belemnites nitidus*, which range into the Kimeridge Clay.

Near Abbotsbury (see Fig. 148) the Sandsfoot Grits pass into ferruginous sandstone and oolitic ironstone, the latter quarried as ore. Similar ironstone occurs at Westbury in Wiltshire, in which county the general succession is:—

		Feet.
Upper Corallian	{ Ironstone Sands and clays }	Upper Calcareous Grit . . 15 to 20 20 to 30
	{ Rubbly oolite and coral beds Calne freestone }	
		Coral Rag . . 20 to 50
Lower Corallian, sands with calcareous burrstones		50

The freestone thins out rapidly north of Calne, and is not present at Faringdon, where the Upper Corallian is not more

than 20 feet thick. In Oxfordshire this stage consists of Lower Calcareous Grit (50 to 60 feet) and Coral Rag (30 to 40 feet), the former consisting of sands with calcareous burrstones, the latter of shelly and coralliferous limestone. But near Stainton St. John these beds change rapidly and appear to be replaced by clays.

In Buckingham, Bedford, and Huntingdon the whole of the Corallian stage is represented by the Ampthill Clay, named from the small town of Ampthill near Bedford. This clay has not yet been separated on the maps of the Geological Survey from the clays above and below, but is shown on a small map illustrating Mr. Rastall's account of Cambridge and Bedford (*Geology in the Field*, vol. i. p. 141), reproduced in *Building of the British Isles* (1911, p. 299). Its fauna includes a mixture of species belonging to the Oxford and Kimeridge Clays with a few that are more especially Corallian. The chief Ammonites are *achilles*, *cordatum*, *plicatilis*, and *vertebralis*; with these are found *Alaria bispinosa*, *Exogyra nana*, *Ostrea deltoidea*, *O. discoidea* (allied to *deltoidea* but more circular), *Gryphea dilatata*, *Cidaris florigemma*, and *C. Smithi*. As seen near Ampthill this division consists of grey marly clay with a bed of nodular limestone $4\frac{1}{2}$ feet thick at the base, and a band of septaria at the top.

Near Cambridge and St. Ives the Lower Calcareous Grit is represented by a bed of dark-grey ferruginous oolitic limestone, known as the Elsworth Rock, from 6 to 8 feet thick, and sometimes in two beds with clay between. This is usually overlain by clays of the Ampthill type,¹⁹ but at Upware, between Cambridge and Ely, there is an isolated mass of undoubted Coral Rag and Coralline oolite, which seems to be part of a true coral reef. One pit exposes coral limestone, with *Thamnastrea arachnoides* and *Isastrea explanata*, *Cidaris florigemma*, *Opis*, *Plicatula*, *Lithodomus*, and other inhabitants of the reef; while another pit is opened in soft yellowish oolite, without corals, but containing *Nucleolites scutatus* and *Holcotypus depressus*. This coral reef is not of large extent, for no such rock was found in a boring $2\frac{1}{2}$ miles north-west of Upware.

The Ampthill Clay was recognised by Mr. Roberts in Lincolnshire. It forms a narrow band between the Oxford and Kimeridge Clays from Bardney on the Witham to Briggs and Wrawby, and it yields the same fossils as in Bedford and Cambridge. Its thickness is not less than 20 feet, and may be more.

In Yorkshire the Corallian attains an unusual thickness and occupies a large area of ground round the Vale of Pickering. It has been specially studied by Messrs. Blake and Hudleston and by Mr. Fox-Strangways, from whose memoir the following tabular view of the succession near Pickering has been taken:—

		Feet.
Zone of <i>Am. plicatilis</i> .	Upper Calcareous Grit, shales, and grit. <i>Cardioceras alternans</i> , <i>Belemnites nitidus</i> , and <i>Goniomya literata</i>	30 to 40
	Upper limestones, coral rags, and oolites with <i>Perisphinctes plicatilis</i> , <i>Bourguetia striata</i> , <i>Trigonia perlata</i> , <i>Cidaris florigemma</i> , <i>Thamnastraea concinna</i> , and other corals	40 to 50
	Middle Calcareous Grit with <i>Perisphinctes plicatilis</i>	40 to 80
	Lower limestones with <i>Cardioceras cordatum</i> and <i>Nucleolites scutatus</i>	30 to 60
Zone of <i>Am. perarmatus</i> .	Graystones, coarse, gritty, and cherty limestones with <i>Aspidoceras goliathus</i> , <i>Gervillia aviculoides</i> , and <i>Rhynchonella Thurmanni</i>	25 to 40
	Lower Calcareous Grit, gritty limestones, and soft calcareous sandstone with <i>Aspidoceras perarmatus</i> , <i>Rhynchonella Thurmanni</i> , and <i>Collyrites bicordatus</i>	50 to 130
		From 215 to 400

3. The Kimeridge Clay.—This formation takes its name from Kimeridge Bay near St. Alban's Head in Dorset, where it has a thickness of no less than 1000 feet and is divisible into—

	Feet.
The Upper Kimeridge or zone of <i>Perisphinctes biplex</i>	600
The Lower Kimeridge or zone of <i>Cardioceras alternans</i>	400

In Dorset and Wilts the lower part consists of dark clays and shales with layers of septaria and cement-stones; these beds yield *Cardioceras alternans*, *Perisphinctes mutabilis*, *Ostrea deltoidea*, and *Rhynchonella inconstans*. The upper beds are black bituminous shales and grey papery shales, often full of broken and compressed shells; they yield *Perisphinctes biplex*, *Protocardia striatula*, *Thracia depressa*, *Exogyra virgula*, and *Lucina minuscula*. Reptilian bones occur throughout the Kimeridge Clay, and among them are remains of two species of Pterodactyles.

There are few good inland sections of the Kimeridge Clay, and its thickness is greatly diminished in passing through Dorset and Wiltshire, for at Swindon it is estimated to be only about 300 feet; and in Berkshire and Oxfordshire it is not much more than 100 feet, but is still divisible into the two zones.

Near Aylesbury the Kimeridge Clay is not more than 100 feet thick, and merges upward into a sandy clay containing Portlandian fossils (the Hartwell Clay). Near Leighton Buzzard, and thence through Bedfordshire, most of the Kimeridge Clay is concealed by the Cretaceous sands, and does not emerge again till we reach the neighbourhood of Papworth in Cambridgeshire, where it appears above the Ampthill Clay, and runs in a narrow belt by Knapwell, Boxworth, and Cottenham to the Fens.

Near Ely this clay has been largely dug, and both zones (upper

and lower) have been recognised. The lower (from 80 to 90 feet) contains *Cardioceras alternans*, *Astarte supracorallina*, *Ostrea deltoidea*, etc.; the upper, of which only 16 feet is seen, contains *Ecogyra virgula* and *Orbiculoidea latissima*, but still higher beds may be concealed beneath the Cretaceous rocks.

In Lincolnshire both lower and upper divisions are well developed, and the whole stage is probably about 600 feet thick. The lower beds are exposed near Horncastle, Wragby, Market Rasen, and Wrawby near Caistor. At Rasen they yield many finely preserved fossils which include *Cardioceras alternans*, *Perisphinctes mutabilis*, *Trigonia Juddiana*, *Inoceramus rasensis*, *Thracia depressa*, and *Nucula Menkei*. The upper beds are mainly shales, seen near Spilsby, Fulletby, and West Ashby, and yielding *Per. bplex*, *Protocardia striatula*, *Lucina minuscula*, *Lingula ovalis*, and *Orbiculoidea latissima*.

In Yorkshire the Kimmeridge Clay is not well exposed, for though it doubtless underlies a large part of the Vale of Pickering, it is concealed by Glacial drifts, and only the highest beds are exposed on the shore at Speeton Gap. These consist of brown and black shales containing *Perisphinctes bplex* (?), *Ostrea gibbosa*, *Discina latissima*, and *Lingula ovalis*.

4. The Portland Beds or Portlandian.—Like the Kimmeridge Clay, these beds are thickest in Dorset and thin northwards. They are well exposed between Durlstone Head and St. Alban's Head (see Fig. 149), where they are divisible as follows:—

		Feet.
Upper Portlandian	Freestone Beds	40 to 50
zone of <i>Holc. giganteus</i>	Cherty Beds	60 to 75
Lower Portlandian	Sandy marls, sands, and calcareous	
zone of <i>Perisph. gigas</i>	sandstone	130 to 160
		<hr/> 230 to 285

The hard sandy marls of the lower group contain *Perisphinctes bplex*, *Ecogyra bruntutana*, *Trigonia incurva*, *Tr. Pellati*, and *Rhynchonella portlandica*. The "cherty beds" are brown earthy limestone with irregular layers and nodules of flinty chert; *Pecten lamellosus* and *Protocardia dissimilis* occur in these beds. The freestones are oolitic limestones, which are largely quarried for building stone; they contain *Trigonia gibbosa*, *Perna mytiloides*, *Cerithium portlandicum*, and *Holcostephanus giganteus*.

At Portland the succession is similar and the total thickness about 220 feet, but at Upwey, north of Weymouth, a different facies presents itself, the whole Upper Portlandian having passed into a white chalky limestone with black and grey flints. This

Fig. 148.—SECTION THROUGH ABBOTSBURY AND LINTON HILL IN SOUTH DORSET (after A. Strahan).

1. Chalk
2. Upper Greensand } Cretaceous.
3. Gault

4. Forest Marble.
5. Kimridge Clay.
6. Abbotsbury Ironstone.
7. Sandfoot Beds.

8. Trigonía Beds.
9. Osmington Oolite.
10. Lower Corallian.
11. Oxford Clay.

Fig. 149.—SECTION ACROSS THE MIDDLE OF THE ISLE OF PURBECK. District about 3 miles.

9. Chalk
8. Selbornean } Cretaceous.
7. Wealden

6. Upper } Purbeck Beds.
5. Middle
4. Lower

3. Upper } Portlandian.
2. Lower
1. Kimridge Clay.

is not more than 30 feet thick, while the sandy beds are about 60 feet, so that the whole is less than 100 feet. In the Vale of Wardour both chalky and oolitic limestones occur, and each division of the stage is from 50 to 60 feet thick.

The next good exposure of the Portland Beds is at Swindon, where the limestones are partly replaced by sands. The beds are exposed in railway cuttings and quarries, and the combined succession is given by Mr. H. B. Woodward as follows:—

		Feet.
Upper Portlandian	Marly and oolitic limestones	6 to 12
	Whitish sands with lenticular layers of calcareous sandstone	20 to 25
	Marly and oolitic limestones with <i>Trigonia gibbosa</i> and <i>Cerithium portlandicum</i>	3 to 7½
	Blue clay weathering brown	14 to 20
Lower Portlandian	Marly sandstone with <i>Exogyra bruntutana</i>	6 to 8
	Sands with doggers of calcareous sandstone	30 to 40
		About 100

In the Midland counties the only good exposures of the Portlandian are in Buckinghamshire near Thame, Brill, and Aylesbury, where they exhibit a special facies different from that of Dorset or Wiltshire. The succession is as follows:—

		Feet.
Upper Portland, 26 feet	Grey marls and thin limestones, <i>Holcostephanus giganteus</i> , <i>Ostrea expansa</i> , and <i>Trigonia gibbosa</i>	8 to 12
	Marly and shelly limestones, <i>Trigonia gibbosa</i>	5 to 8
	Greenish-yellow sand	5 to 6
	Marly and rubbly limestone with fossils	10 to 15
	Yellowish-green sand with a bed of small pebbles of quartz and lydianite at the base	8 to 10
Hartwell Clay	Fine sandy clay with <i>Astarte hartwellensis</i> , <i>Cardium morinicum</i> , <i>Perna Bouchardi</i> , <i>Trigonia Pellati</i>	20 to 30

Near Thame there are yellow and green sands below the pebble-bed, but these thin out or pass into clay northward; the Hartwell Clay being apparently the equivalent of the Portland Sands.

The most northerly outlier of these beds is at Stewkley Warren, 4 miles west of Leighton Buzzard, where about 15 feet of them, capped by a few feet of Purbeck Beds, was at one time exposed. Beyond this they are not seen either in Bedford, Cambridge, Norfolk, or Lincoln, but derived and phosphatised Portlandian fossils are of frequent occurrence in the Lower Cretaceous sands, and consequently it is most probable that they originally extended through these counties, but were destroyed at the beginning of the Cretaceous period.

In Yorkshire, at Speeton, the Kimeridge Clay is surmounted

by a bed of black phosphatic nodules, the "coprolite bed," and the clays above this contain Ammonites which resemble Portlandian species, so that the beds have been classed by some as Portlandian. As, however, the Ammonites are not identical with Portlandian forms, and as the Neocomian Belemnite (*B. lateralis*) occurs throughout, with *Hoplites regalis* in the higher part, the beds are probably of Lower Cretaceous age (see p. 484).

5. The Purbeck Beds.—The typical Purbeck Beds are only found where the Portland Beds are completely developed. They are a variable set of beds exhibiting alternations of terrestrial, freshwater, brackish-water, and estuarine conditions, the changes from brackish to freshwater deposits being generally gradual, while the reverse changes are abrupt, indicating sudden inroads of the sea. In Durlston Bay, near Swanage, these beds are 400 feet thick, and have been divided into Lower, Middle, and Upper Groups, characterised respectively by *Cypridea purbeckensis*, *C. granulosa*, and *C. punctata* (see Fig. 149). The following is a summary of the cliff section:—

		Feet.
Upper, 80 feet	Grey and purple marls with <i>Viviparus cariniferus</i> . . .	14
	Shales with beds of Paludina limestone (Purbeck marble), <i>Cypridea</i> abundant . . .	45
	Unio Beds and shelly limestones with <i>Viviparus</i> . . .	15
	Alum-shales and thin limestones with layers of gypsum, <i>Corbula</i> , <i>Cyrena</i> , <i>Cyclas</i> , etc.	64
Middle, 155 feet	Hard shelly limestones with partings of shale, fossils of marine and estuarine species	50
	Cinder bed, a mass of <i>Ostrea distorta</i>	9
	Thin limestones, marls, and shales with remains of insects, fish, and freshwater shells; at the base is a black shale with mammalian remains	43
	Marly freshwater beds, <i>Physa</i> and <i>Planorbis</i>	7
Lower, 170 feet	Marls and marly limestones with <i>Cardium</i> , <i>Corbula</i> , <i>Cyrena</i> , and <i>Cypridea</i>	92
	Marly limestones and shales, with <i>Cypridea</i>	36
	Beds of broken slaty limestone	15
	Brown bituminous limestones with a layer of dark earth (dirt bed) resting on Portland stone	19
		<hr/> 409

The same series can be seen in Worbarrow Bay, Mupe Bay, and Lulworth Cove, but it becomes thinner to the westward, 250 feet at Mupe Bay, only 176 feet at Lulworth, and at Ridgeway Hill 190 feet.²⁰

The lowermost beds are well exposed in the quarries at Portland, where the most remarkable stratum is the upper "dirt bed," which is a dark-brown loamy earth—an actual soil or terrestrial surface, in which cycads and coniferous trees are still rooted.

The Purbeck Beds are cut off and faulted against the Chalk and Greensand by the great Ridgeway fault, and they are not seen again till they crop out in the Vale of Wardour (Wilts). The succession in this area, as described by Mr. W. R. Andrews and myself in 1894,²¹ with such subsequent corrections by Mr. H. B. Woodward²² as we accept, is as follows:—

		Feet.
Upper	{ Clays, marls, and shelly limestones with <i>Cypridea punctata</i> , <i>Cyrena media</i> , and <i>Unio</i>	10
	{ Yellow sand and grey clay	12
Middle	{ Sandy and marly limestones, shelly marls, and cinder bed with <i>Ostrea distorta</i> and <i>Trigonia gibbosa</i>	12
	{ Limestones and shelly marls, <i>Cypridea granulosa</i>	11
Lower	{ Marly limestones (locally known as Lias) with layers of shaly marl, <i>Cypris purbeckensis</i>	20
	{ Pale yellow oolitic limestones and marls	25
	{ Grey laminated marls and limestones	20
Total about 110

Fig. 150.—DIAGRAMMATIC VIEW OF THE SWINDON QUARRIES (after Professor J. F. Blake).

g, h, i. Purbeck Beds.
c, d, e, f. Portland limestones.

b. Sand with calcareous doggers
a. Portland limestone.

The Lower Purbeck Beds are seen again at Swindon, where they rest partly on the Upper Portland and partly on the Portland sands (see Fig. 150), and their basement bed contains rolled lumps of stone derived from the Portland Beds.

In the Midlands the Purbeck Beds only emerge from beneath the Cretaceous strata in Oxford and Bucks. Around Thame, Aylesbury, Brill, and Whitchurch the Portland Beds are succeeded by a variable group of beds with freshwater fossils, which are generally considered to be of Purbeck age. They consist of a variable series of thin-bedded limestones, marls, shales, clays, and calcareous sands, but do not exceed 30 feet in thickness, and probably represent the Lower Purbeck only, the higher beds having been removed by Cretaceous erosion. They have yielded remains of Plants, Insects, and Cyprides, with *Viviparus*, *Cyrena*, *Modiola*, and the fish *Lepidotus minor*, *Pleuropholis serrata*, *Aspidorhynchus*, and *Mesodon*.

The only other part of England where Purbeck Beds have been found is in Sussex north-west of Battle, where narrow strips of them are brought up by anticlinal flexures from below the Wealden Beds. They consist of shales with beds of limestone which were formerly quarried, and the succession proved by shafts and given by Mr. Topley²³ is:—

	Feet.
Shales with beds of limestone and some of calcareous sandstones,	
<i>Cyp. punctata</i> and <i>C. granulosa</i>	80
Black, grey, and greenish shales with ironstone nodules	130
Bluish-grey limestones and shales, with <i>Ostrea</i> , <i>Cardium</i> , <i>Cyrena</i> , and other fossils	75
Shales with many beds of gypsum	130
	415

Purbeck Beds have also been traversed by many of the borings which have recently been made in Kent, and the records show that the group thins both to the north and east. Thus at Pluckley, about 16 miles north-east of the outcrops in Sussex, they are only 100 feet thick, and at Brabourne, about 10 miles farther east, they have diminished to about 60 feet. They were not found in any of the borings to the north or east of that place, though this may be due to the planing off of beds below the Vectian sands.

D. THE UPPER JURASSIC SERIES IN SCOTLAND

West Coast.—The only member of the Upper Jurassic series which is found on the west coast of Scotland is the Oxford Clay. This overlies the great estuarine series in the islands of Skye and Eigg, and consists of blue clays containing *Cardioceras cordatum*, *Card. excavatum*, *Quenstedticeras Lamberti*, and others. Above it are Cretaceous rocks.

East Coast.—In Sutherland a much more complete series is found; the beds are seen at intervals along the coast for a distance of 16 miles, and form a narrow strip of low ground which is bounded inland by a powerful fault, and has an extreme width near Brora of about 2 miles. In this small space is found a succession of beds representing the whole of the Oxford Clay, Coral Rag, and part of the Kimeridge Clay, as below:—

		Feet.
Kimeridge Clay	Light-coloured sandstone; no fossils	100
	Shelly limestones, black shales, and grits with <i>Belemnites abbreviatus</i> , <i>Cardioceras alternans</i> , <i>Perisphinctes biplex</i> , and many others; ferns, cycads, and conifers	500
	White sandstones and carbonaceous shales; estuarine beds with few fossils	200
	Grits and sandstones; <i>Perisphinctes biplex</i> , <i>Per. mutabilis</i> , <i>Reineckia eudoxus</i> , and <i>Belemnites obeliscus</i>	? 200

		Fect.
Corallian	Grey limestones and sandy clays in two bands, separated by 60 feet of white sandstone; <i>Cardioceras cordatum</i> , <i>C. excavatum</i> , <i>Trigonia corallina</i>	150
	White sandstones with bands of lignite and occasional layers containing casts of marine shells; estuarine beds	400
	White cherty sandstones with many fossils, <i>Aspidoceras perarmatum</i> , <i>Perisphinctes achilles</i> , etc.	25
Oxford Clay	Sandy clays and black shales with <i>Belemnites Oweni</i> , <i>Bel. hastatus</i> , <i>Cardioceras ornatum</i> , <i>Cosmoceras Duncanii</i>	300
	Sandy shales, with <i>Nucula nuda</i> , <i>Kepplerites gowerianus</i> , and <i>Kepplerites calloviensis</i>	5
	Calcareous sandstone with many fossils, fauna of Kel-laways Rock	5

E. CONTINENTAL EQUIVALENTS

1. Northern and Eastern France

In the great Parisian basin the general facies of the Upper Jurassic Series is similar to that of England, except that it is more calcareous. It can be divided into a similar series of zones and sub-stages, but unfortunately the original English divisions were not founded on zones but on local lithological differences, and though the English names have been widely adopted on the Continent, they have become attached to groups of strata which do not exactly correspond with the English divisions.

Some adjustments of nomenclature will be required on both sides of the Channel in order to bring the names of the several stages into accord. Thus French geologists have created two stages, a *Callovian* and an *Oxfordian*, but the latter is the zone of *Aspidoceras perarmatum* and equivalent to the Lower Corallian of England; while the Callovian includes the *ornatum* clays, though these have since been separated as a sub-stage under the name of *Divesian*. Thus their Callovian is practically our Oxfordian.

Again there has been much confusion about the correlation of the equivalents of the Corallian and Kimeridge Clay in France, for the beds which represent our Upper Calcareous Grit are known as the *Astartian* or *Sequanian*, and have been classed in some places with the Corallian and in others with the Kimeridgian limestones. De Lapparent, following Tombeck, dropped the name Corallian altogether, and advocated an expanded *Sequanian* as its substitute; but Messrs. J. F. Blake and T. Roberts, who both carefully studied the Upper Jurassic Series of Eastern France and the Jura, agree in thinking that the *Astartian* is more closely allied to the Kimeridgian than to the Corallian.²⁴

On the other hand, they agree that the English Kimeridge

Clay is an exceptional argillaceous facies, and that it is represented in France and in Germany by thick masses of limestone and marl which belong to several sub-stages or zones. Even in Normandy and the Boulonnais the highest part of our Kimeridge Clay is represented by calcareous sandstones which are faunistically linked to the Portlandian stage.

Lastly, French geologists regard the Purbeck Beds as a subordinate portion or sub-stage of an expanded Portlandian stage, and they have good reason for this because the marine equivalents of the Purbeck Group contain a fauna which is closely related to that of the Portlandian.

The student will now be able to understand the following tabular correlation of the succession found in France and in the Jura Mountains with the English subdivisions, these and the French divisions having the value of sub-stages.

	England.	Paris Basin.	Jura.
4.	{ Purbeck Beds Portland Beds Clays with <i>Discina</i> }	Purbeckian	Marls and limestones.
		Bononian	Massive limestones.
3.	{ Clays with <i>Ex. virgula</i> Clays with <i>A. alternans</i> Sandsfoot Beds, etc. }	Virgulian	Compact limestones.
		Pteroceran	Pale limestones.
		Astartian	Grey limestones and marls.
2.	{ Corallian limestone Lower Calcareous Grit }	Corallian	Corallian limestones.
		Oxfordian	Oxfordian limestones.
1.	{ Oxford Clay Kellaways Beds }	Divesian	Ironstone and clay
		Callovian(restr.)	Rough limestone.

It will be seen that a good correlative grouping of these sub-stages into four stages would be made in accordance with the brackets, and that these stages could be called respectively (1) Oxfordian, (2) Corallian, (3) Kimeridgian, (4) Portlandian. The total thickness in the Jura is not more than 1200 feet.

The most important and interesting groups are the Corallian, the Pteroceran, and the Purbeckian. The *Corallian* swells out in Lorraine, Burgundy, and the Jura, and includes thick masses of coralliferous limestone, often over 300 feet thick, which the French regard as true coral-reefs; they contain *Diceras arietinum*, *D. eximium*, with *Comoseris mæandroides*, and other corals.

The *Pteroceran* in the Ardennes, Meuse, and Aube consists of clays, marls, and limestones with *Perisphinctes decipiens* and *Exogyra virgula*, not very different from the corresponding part of our Kimeridge Clay; but southward they are replaced by massive limestones and marls containing a different set of fossils, especially *Harpagodes Oceani*, *Natica gigas*, *Pholadomya Protei*, and *Hemicidaris Thurmanni*.

The Purbeckian is divisible into two parts, the lower, about 150

feet thick, consisting of dolomitic limestones containing *Cyrena rugosa*, *Corbula inflexa*, and other marine species, the upper being a few feet of marl with brackish and freshwater fossils; and these beds pass up into the Valenginian, which is classed as Lower Cretaceous, but may represent the highest part of our Purbeckian as well as some of the Wealden.

2. Germany

The Upper Jurassic Series is well developed in Hanover, and extends westward into Westphalia beneath the Cretaceous deposits. The succession established by the labours of Seebach and Credner has been compared with the English Series by Dr. C. Struckmann, and the following table is compiled from his memoir, a translation of which will be found in the *Geol. Mag.* for 1881, p. 546.

Port- landian	{	Serpulite limestone, 10 to 60 feet	} Lacustrine Beds.
		Mundermergel, gypsiferous marls	
		Plattenkalk of Eimbeckhauser (platy limestones).	
Kime- ridgian	{	Limestones and marls with <i>Perisphinctes gigas</i> .	
		Virgula Beds, compact and oolitic limestones.	
		Pteroceras Beds, limestones with <i>Harpagodes Oceani</i> .	
Corallian	{	<i>Nerinea</i> Beds (= Astartian), limestones.	
		Upper Cor. limestones (zone of <i>Pecten varians</i>).	
		Lower Cor. limestones (zone of <i>Ostrea rustellaris</i>).	
Oxfordian	{	Hersumer Beds. Sandy beds with <i>Aspidoceras perarmatum</i> , <i>Cardioceras cordatum</i> , and <i>Gryphaea dilatata</i> .	
		Clays with <i>ornatus</i> Ammonites.	
Callovian	{	<i>Macrocephalus</i> Beds, clays and ironstones.	

It will be seen that the greater part of the series consists of limestones with some clays at the bottom and a remarkable development of marls near the top; these are of red and green colours and much resemble the marls of the Keuper; they are from 400 to 500 feet thick in Hanover, but thicken westward to over 1500 feet in Westphalia, where they include limestones full of *Corbula*, *Vivipara*, and *Cyclas*, as well as beds of gypsum and rock-salt. The Serpulite limestone is full of small *Serpula* tubes, but also contains *Corbula*.

In the south of Germany (Swabia and Franconia) the Upper Jurassic Series is again found, but has a different palæontological facies. Its thickness is only from 800 to 1000 feet, and the succession of zones is as below:

		Feet.
Port.	{ Zone of <i>Oppelia steraspis</i> and <i>Perisphinctes gigas</i> , (Plattenkalk and Solenhofen limestones)	80
	{ Zone of <i>Exogyra virgula</i> , including the coralliferous limestone of Nattheim	about 150
Kim.	{ Zone of <i>Reineckia cudozus</i> (limestones)	100
	{ Zone of <i>Oppelia tenuilobata</i> (marly limestones)	130

	Feet.
Cor. —Zone of <i>Peltoceras bimammatum</i>	about 80
Oxf. { Zone of <i>Peltoceras transversarium</i> and <i>Waldheimia</i> <i>impressa</i> (marls, clays, and limestones)	140 to 350
Cal. { Zone of <i>Ornatus</i> Ammonites (clays), with <i>Macro-</i> <i>cephalus</i> limestone at base.	

The most interesting member of this series is the lithographic limestone of Solenhofen, which must have been deposited in very quiet and clear water and not far from land; for though it is of marine formation and contains several species of Ammonites and Belemnites with Crabs, Starfish, and other sea-creatures, it also encloses entire skeletons of Pterodactyles and the remains of the curious bird *Archæopteryx* (see p. 384), as well as the remains of dragonflies, cockroaches, wood-wasps, and ordinary flies (*Musca* and *Empidia*); all in the most beautiful state of preservation owing to the fine grain and slow deposition of the limestone.

3. The Alpine Facies

In the Alpine region the lower part of the "Upper Jura" has but a small development; the Callovian, Oxfordian, and Corallian being only represented by bands of limestone which do not always contain the characteristic species of Ammonites. The higher portion of the series, however, swells out into a massive series of limestones from 1000 to 2000 feet thick, which form a special facies of the Kimeridgian and Portlandian stages. At the base of these beds are limestones which frequently contain *Oppelia tenuilobata*, and consequently represent the Lower Kimeridgina (or Astartian). The middle part of the series consists of reddish

Fig. 151.—TEREBRATULA DIPHYA.

limestones so full of *Terebratula diphya* (now called *Pygope janitor*) that they are known as the Diphya limestone. The upper beds are massive pale-coloured limestones, often called the Stramberg limestone from Stramberg in Moravia, and they also contain *Pygope janitor* as well as Ammonites, Diceras, Nerinæas, and Corals.

These Diphya limestones are sometimes called the Tithonian or the Tithonic facies of the Portlandian, for they contain the Portlandian Ammonoids *Oppelia steraspis* and *Oppelia lithographica*

as well as other peculiar species, such as *Phylloceras pychoicum* and *Waagenia hybonota*. In the Stramberg limestone *Phylloceras silesiacum* and *Perisphinctes transitionis* also occur, and this limestone may be the equivalent of our Purbeckian. This facies extends from the Central Alps and the north of Italy through the Tyrol and Austria to the Carpathians and is found also in the Balkan States.

4. The Russian Facies

As already stated the oldest Jurassic deposits in Russia are of Oxfordian age, and the fauna of these and the succeeding Corallian and Kimeridgian Beds is similar to that of their equivalents in Western and Central Europe; the highest part of the series forms a special Russian or Boreal facies, differing in so many respects from the normal Portlandian that Nikitin proposed the name *Volgian* for this set of beds. Although the thickness of the group is very small—only a few feet of sand and shale with layers of phosphatic nodules—several Ammonite zones have been detected in it, and it passes up into beds of Lower Cretaceous age.

The beds were evidently formed in shallow water and under the influence of strong currents. The prevalent genera of Ammonites are *Perisphinctes*, *Virgatites*, *Holcostephanus*, and *Craspedites*, with Belemnites of the *absolutus* type and shells of the bivalve *Aucella*.

The best sections are near Moscow and in the province of Simbirsk, especially between Simbirsk and Syrzan on the Volga, where, however, the beds are very thin, the succession according to Professor Pavlow being as follows in descending order:—

4. Calcareous sands with <i>Craspedites subditus</i>	? 6 feet
3. Glauconitic sand with <i>Holcostephanus Bladei</i> , <i>Holc. triplicatus</i> ,
and <i>Perisphinctes cf. gigas</i>	1 "
2. Sand with phosphate nodules and shales with <i>Virgatites virgatus</i> , <i>Belemnites absolutus</i> , etc.	3 "
1. Shales with <i>Perisphinctes Bleicheri</i> and <i>Aucella Pallasi</i>	2 "

The *subditus* zone is correlated by Pavlow with the Purbeck Beds, but this is uncertain (see p. 491). It will be noticed that the underlying Portlandian is only 6 feet thick, but near Moscow the corresponding beds have a thickness of 26 feet.

HISTORY OF THE JURASSIC PERIOD

Liassic Time.—We have seen that it is convenient to date the beginning of this period from the subsidence which permitted the Southern Sea to make its way into the great Inland Sea which

occupied so large a part of Northern Europe in later Triassic time. The level of the water in the Inland Sea seems to have been somewhat below that of the outer ocean, because the Rhætic Beds here and there pass beyond the limits of the Keuper, but the difference of level cannot have been great, and the invasion of the area by the outer sea seems to have been accomplished quietly and with little disturbance of previously formed deposits. The sea-waters simply occupied the basins and embayments of the great lake, in which shales and limestones began to be deposited.

It is clear, however, that the mingling of sea and salt-lake waters resulted at first in the death of many of the creatures which inhabited both. The fish and marine reptiles which came in from the sea could not exist in the highly saline mixture, and their remains are found in the bone-bed which so often occurs at or near the base of the Rhætic Beds. Neither could all the Mollusca which came in with them flourish in the land-locked waters, and those that managed to exist are small in size, as if dwarfed by unfavourable conditions.

In some localities there are several bone-beds at successive horizons, suggesting that there were several invasions of the sea over the barrier which separated the inner from the outer waters. Such irruptions may have taken place at conjunctions of high tides and southerly winds. Moreover, in Alsace and Lorraine, and again in Glamorgan, the Rhætic sandstones and bone-beds are overlain by a band of red marls exactly like those of the Keuper, from which we may infer that communication with the outer sea was not yet permanent, and that there was a time when the area of the inland sea was again diminished by evaporation so that portions of it returned to the condition of separate salt lakes.

At length a further subsidence brought in such a body of sea-water that permanent marine conditions were established, and many forms of life were able to inhabit the northern water-spaces. It was under these conditions that the shales and limestones of the Lower Lias began to be deposited.

The material of the shales was probably obtained from the erosion of Palæozoic shales, and more especially from those of the Coal-measures, large tracts of which must then have existed as part of the continental land to the west and north of the Liassic Sea. During the Permian and Triassic periods the climatic conditions had been like those of Central Asia at the present day, with a small rainfall, but in Liassic time it is evident that the climate was greatly changed, and that much more rain fell over the whole region, so that active erosion went on, and the rivers carried much mud into the Liassic Sea.

With respect to the limestones, it is noticeable that they are thin-bedded and compact and mostly of an earthy or argillaceous nature, so that they must have been originally more or less calcareous muds. Hence it is probable that the calcareous matter had a chemical or sedimentary rather than an organic origin. Mr. H. B. Woodward thinks they may have been derived mechanically from the waste of Palæozoic limestones,²⁵ but it is more likely that the conditions were favourable to the chemical precipitation of carbonate of lime from solution.

The geographic arrangement of land and sea in Liassic time was at first only a modification of that which prevailed in Keuper time (see Fig. 124); but the sea gradually extended itself over a larger area. There is no evidence that the Lower Lias occurs under the northern part of the Paris basin, and there is no trace of it in the Boulonnais. In Normandy it only occupied what may be called the bay of Carentan, and does not occur near Caen. The Middle Lias, however, extends much farther south, patches of it being found at intervals in the Departments of Calvados, Orne, Sarthe, and Maine, while Upper Lias has been reached in a deep boring at Rouen. Thus it appears that by the time of the Middle Lias a channel of communication had been established between the British Sea and that which spread over the greater part of France.

There were, however, two large islands in this western part of the Liassic Sea. One of these was the central plateau of France; proof of this is found in the fact that the Charmouthian deposits, in the form of sands and conglomerates, overlap the Sinemurian at many places round its borders, and rest directly on the Archæan rocks. Similarly in Poitou, near Thouars, the Toarcian in its turn passes beyond the Charmouthian as a consequence of continued subsidence. The other island lay farther north; it comprised a part of Eastern England and the southern part of the North Sea, with the north-east of France and the whole of Belgium.

The Liassic Sea seems to have occupied the whole of Germany and Central Europe, as well as Italy and the greater part of Spain, and it extended eastward through Hungary to the Carpathian Mountains, and through Transylvania to Kronstadt, but it does not seem to have reached so far east in Northern Europe, for no Liassic deposits have yet been found in Poland or Western Russia.

Glevanian Time.—In the west of Europe and in those places where the succession of marine deposits is most complete, as in the south-west of England, the north of France, and the Jura Mountains, there is a more or less rapid change from Liassic Clays through sands to limestones. There is also a considerable change in the fauna, and it is evident that the sea-water became clear where it had been

muddy, and in consequence a new fauna was able to establish itself in French and British Seas.

The cause of this change, so far as the British area is concerned, has been discussed in my *Building of the British Isles*, the conclusion arrived at being that there was first a slight uplift of the whole area, whereby river-erosion was checked, and that this was followed by unequal movements, some parts of the region being further raised and others depressed. These inferences appear to be applicable also to Northern France (Normandy and the Boulonnais), but not so much to the central or southern parts of that country.

Both the Bajocian and the Bathonian are well developed round nearly the whole circumference of the Central Plateau. On the northern border they consist entirely of limestones, the Bajocian being from 150 to 250 feet thick, and the Bathonian from 300 to 400. In the Côte d'Or and along the eastern side of the Plateau the composition and thickness are similar, while on the south, in the Causses district (Tarn and Aveyron), they are represented by massive limestones which have an aggregate thickness of 1200 feet. It is only on the south-west that the marine limestones are thin and are interstratified with estuarine deposits.

No overlap of the Lias by Bajocian or Bathonian has been recorded, so far as I can ascertain, though it must have taken place, and we may safely conclude that after some slight disturbances subsidence proceeded in this part of France, and that the central island was greatly reduced in size. The greatest subsidence was clearly over the Mediterranean and Alpine region, and a broad communication was opened up, through Provence, Dauphiny, and the Jura, between the northern seas and a warm southern sea, by means of which numerous Corals, Brachiopoda, Gastropoda, and Cephalopoda made their way into the Franco-British areas.

The Belgian island still continued to exist, though the overlap of the Bathonian in Kent and the Boulonnais shows that its area was diminished to some extent. There is evidence of another island having existed in Servia near Milanovitz, and there may also have been others within the European region.

The whole of Northern Russia and the whole of Scandinavia appear to have been land, into the western border of which small gulfs penetrated from the Central European Sea.

Clavinian Time.—With respect to the early part of this epoch there can be no doubt that it witnessed a still more rapid subsidence of the whole European region, a subsidence which submerged islands and carried the sea eastward across Central Russia into Asia. This change is only partially expressed in De Lapparent's maps, for though he indicates the extension of the Callovian Sea

through Russia and northward to the Arctic Ocean, the islands in the western part of this sea are not only retained, but are scarcely diminished in size; moreover, in his "Sketch of Oxfordian Europe" they have actually grown larger.

British geologists believe that the subsidence of the Callovian or beginning of Oxfordian time was a general one, affecting the western as much as the eastern parts of Europe. It is probable that the Upper Jurassic Clays spread over the whole platform of Palaeozoic rocks which underlies the east of England, and that these clays were subsequently removed partly by subaerial erosion and partly by the planation of the area as it sank beneath the Upper Cretaceous Sea. My view is that the whole of the Anglo-Belgian island was submerged beneath the seas of Oxfordian, Corallian, and Kimeridgian times, and did not reappear until the Portlandian, for the thinning of the Corallian and Kimeridge Beds in the Boulonnais is doubtless due to their subsequent planation and not to their originally thinning out against a shore-line.

Another question arises with regard to the northern extensions of the Oxfordian and Corallian Seas, for some have supposed that the connection between Scotland and Scandinavia was severed at this time and that the Scandinavian region, together with Lapland and Finland, became a large island. There can be no doubt that the Middle Jurassic Sea did pass round the eastern and northern sides of this land, for not only are there deposits of this age in Northern Russia in the province of Volodka, but also to the north-east of the White Sea and in the valley of the Petchora. They also occur in König Karl Land and Spitzbergen, forming a succession from Callovian to Kimeridgian, and beds of Oxfordian age have been found on the east coast of Greenland (Kuhn Island and Jameson Land).

Hence it is quite possible that the Boreal Sea of Oxfordian time did extend southward to Scotland and thus encircled the Scandinavian region, but it is much more probable that the connection with the Germano-British Sea was round the western side of Scotland and across the north of England than directly between Scotland and Norway. The Jurassic strata of the Western Isles were undoubtedly formed in a sea which covered the north-western arm of the great Triassic lake, and there is no reason to suppose that Jurassic deposits were ever formed in the east of Scotland south of Elgin or in the south-west of Norway. The Kimeridgian Beds of Sutherland seem to have been formed in the estuary of a river which may have opened either northwards into the Boreal Sea or south-westward down the valley of the Great Glen. I see no reason for supposing that the Central Highlands

of Scotland were severed from their original connection with Norway in the Jurassic period, or that any sea flowed between the two areas until the great submergence of the Cretaceous period.

The Corallian episode probably indicates a pause in the subsidence or a diversion by some other means of the mud-bearing currents, so that for a time they did not pass over Southern or Northern England though they continued to traverse the intervening space. But matters reverted to their former condition in Kimeridgian time, and the geographical arrangement of land and sea must have continued to be practically the same.

The Portlandian deposits, however, give evidence of a great change and of a reverse movement by which the sea-floor was shallowed over the whole of Northern and Western Europe, large parts of it being once more raised into dry land. Thus a western land was formed again in the North Atlantic which included the greater parts of Britain, France, and Spain; the Anglo-Belgian island again came into existence, and was only separated from the western land by a narrow strait running through the counties of Bedford, Huntingdon, and Cambridge.

The Boreal Jurassic Sea must have retreated northward, but for a time there still remained an arm or gulf extending from Germany across the North Sea area into Yorkshire and Lincolnshire, but the later Portland and Purbeck deposits of Hanover show that this gulf was shallow and was soon converted into a plain with lagoons and freshwater lakes.

Southern Europe was much less affected by this Portlandian and Purbeckian elevation, and marine limestones continued to be formed in a southern (Tithonian) sea which was nearly as extensive as it had been in Oxfordian and Corallian times. From this sea a gulf extended through the east of France and across the Parisian plain to terminate in the estuarine lagoons wherein the English Purbeck Beds were deposited.

The final phase of Jurassic geography was the establishment of a North Atlantic and North European continent, and the gradual transformation of the Purbeck lagoons into the Wealden lake by the continued uprise of the whole surrounding region.

In conclusion, reference should be made to Neumayr's theory that there is evidence of the existence of climatic zones in Upper Jurassic time.²⁶ From the brief review of European deposits which has been given on pp. 451 to 455, it will be seen that they can be grouped under three different facies: (1) a Mediterranean or Alpine; (2) a more northern facies found in Germany and Poland, in Northern France, and in England; (3) a Boreal facies occurring in the north of Russia, Spitzbergen, and Greenland. Neumayr has

pointed out that these three latitudinal facies are not confined to Europe but are traceable in other parts of the world; thus the Boreal facies extends from Russia through Turkestan into Tibet, and recurs in North America; the temperate type recurs in the Caucasus and the Himalaya, and again in California; while the Mediterranean type is found in Asia Minor, Algeria, and Abyssinia, and again in Mexico.

Moreover, in the southern hemisphere the Jurassic deposits found in South Africa, Argentina, New Zealand, and Australia contain a fauna which does not resemble that of the Mediterranean or Equatorial facies, but is very similar to the assemblage of genera occurring in the corresponding beds of England and Germany. The facts, therefore, so far as they are known, certainly tend to confirm Neumayr's view.

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- ²⁴ J. H. Blake, *Quart. Journ. Geol. Soc.* vol. xxxvii. p. 497 (1881); and T. Roberts, *Quart. Journ. Geol. Soc.* vol. xliii. p. 229 (1887).
- ²⁵ H. B. Woodward, "Jurassic Rocks," vol. iii. p. 28.
- ²⁶ Neumayr in *Densch. Wien. Akad.*, vol. xlviii. p. 277 (1883), and vol. l. p. 57 (1885).

CHAPTER XIV

THE CRETACEOUS SYSTEM

A. NOMENCLATURE AND SUBDIVISIONS

THIS system takes its name from *creta*, the Latin word for chalk, because this well-known rock forms a conspicuous part of the system in Western Europe. Beneath the chalk, however, there is a variable series of marine sands and clays, and below these in the south of England there is a great thickness of freshwater deposits which have long been known as the *Wealden*, from the large area occupied by them in the Weald of Kent and Sussex. In the British area it is only in Yorkshire and Lincolnshire that marine deposits of the same age as the Wealden are found, but in other parts of Europe they attain a great thickness.

The system is divisible into two great series, a Lower and an Upper. On the European continent the whole system consists of marine deposits, and a complete sequence is also found in the north of England (Lincolnshire and Yorkshire), but in the south of England the lower part is represented by the freshwater *Wealden Beds*, overlain by some marine deposits which were formerly and are still often called the Lower Greensand, but for which *Vectian* is a much better name.^a

The marine facies of the Lower Cretaceous Series is most fully developed in the south of Europe, and the nomenclature of its divisions is taken from places in the south of France and in Switzer-

^a It is high time that the names Upper and Lower Greensand were abandoned, for they were proposed by Webster at a time (1824) when the beds between the Chalk and the Wealden were regarded as the "Greensand Formation." Thus they only perpetuate erroneous views of classification, and are, moreover, cumbrous and misleading, for the "Lower Greensand" is more often yellow or brown than green. Hence it is desirable that the name *Vectian* (altered from the *Vectine* of Fitton) should be adopted instead of Lower Greensand, while the "Upper Greensand" falls into the group of beds for which the name *Selbornian* has recently been proposed.

land. The lower portion of the series is often called the *Neocomian*, from Neuchâtel in Switzerland, where the beds were first studied and described, but this Neocomian has since been subdivided into two parts, the *Valenginian* and the *Hauterivian*, which seem to have the value of separate stages. The *Barremian* takes its name from Barrême in the Basses-Alpes, and the *Aptian* from Apt in Vaucluse.

The Upper Series includes the *Selbornian*, to part of which the French *Albian* corresponds, and the several stages of the *Chalk* which have received special names on the Continent, but are in England generally known as the Lower, Middle, and Upper Chalk. The stages recognised in Western Europe are tabulated below and correlated with their British representatives.

Western Europe.	Southern England.	Northern England.
Danian . . .	Wanting . . .	Wanting.
Senonian . . .	Upper Chalk . . .	Upper Chalk.
Turonian (restricted)	Middle Chalk . . .	Middle Chalk.
Cenomanian . . .	Lower Chalk . . .	Lower Chalk.
Albian . . .	Selbornian . . .	Red Chalk.
Aptian . . .	Vectian . . .	Upper Speeton clay.
Barremian	Wealden . . .	{ Middle Speeton clay. Lower Speeton clay.
Hauterivian		
Valenginian }		

The relation of the Cretaceous strata to the underlying formations is an important matter. Throughout the greater part of England there is a marked break and unconformity between the Jurassic and Cretaceous Systems, and even in Yorkshire the apparent conformity is probably deceptive, for there is nothing there which can safely be correlated with the Portlandian, and it is very doubtful whether there is any representative of the Purbeck Beds. It is only in the south of England, where the highest Jurassic Beds are fully developed, that a complete sequence of deposits is found to fill up the gap between the two systems, but these deposits are of freshwater origin and do not bridge over the gap in the marine succession.

This gap was undoubtedly caused by the elevation of the greater part of the British region into dry land, a land which extended southward into France and eastward through Belgium; and it was only after a long period of time, marked by the formation of several thousand feet of marine deposits in the south of Europe, that parts of this land were again submerged and that marine deposits were laid down all across England. This change was the commencement of a great subsidence which eventually carried the Cretaceous Seas over the greater part of Europe.

B. LIFE OF THE PERIOD

Flora.—Comparatively few traces of the vegetation of the period are found in the Cretaceous rocks of Britain except in the Wealden Beds, in which, as in the Jurassic System, the predominating groups are ferns and cycads. A few conifers, horse-tails (*Equisetaceæ*), and a *Chara* also occur, but Dicotyledons are unknown, although a few, the earliest of their class, have been found in the Lower Cretaceous rocks of Spain and of North America.

The flora of the Wealden presents a considerable resemblance to that of the Jurassic strata, but as the early Cretaceous continent was only an extension of the Upper Jurassic land, such a resemblance should not cause any surprise.

In the Upper Cretaceous of the Continent Dicotyledons form an important part of the flora, and include a number of genera which have living representatives, *e.g.* *Acer* (maple), *Cinnamomum* (cinnamon), *Ilex* (holly), *Quercus* (oak), *Platanus* (plane), *Hedera* (ivy), *Populus* (poplar), *Myrica* (myrtle), with *Aralia*, *Magnolia*, *Eucalyptus*, and the extinct genus *Credneria*. Cycads are less numerous than before; subsequently they became rare in Europe, and at the present day are chiefly found in the tropical and sub-tropical parts of Asia, Africa, Australia, and Mexico.

Fauna.—The general aspect of the Cretaceous fauna resembles that of the preceding Jurassic much more than that of the succeeding Eocene. Throughout the Lower Cretaceous Series many genera which were abundant in Jurassic times are still common, such as *Cucullæa*, *Trigonia*, *Gervillia*, *Perna*, *Pecten*, *Lima*, *Pleuromya*, and *Pleurotomaria*. The Ammonoid genera *Holcostephanus* and *Perisphinctes* continue to be abundant, and the *Belemnitidæ* were nearly as common, but many new genera of Cephalopoda appear, some in the lower and some in the upper division of the system. The Echinoid genera *Holactypus*, *Nucleolites*, and *Pygurus* also survive into the Lower Cretaceous, but many new genera make their appearance (see list below).

Passing to vertebrate animals, most of the Lower Cretaceous fish belong to genera which existed in Jurassic times, but *Edaphodon*, *Lamna*, and *Protosphyræna* now appear, while in the Chalk many Teleostean fish resembling modern genera are found, such as *Hoplopteryx*, *Osmeroides*, *Enchodus*, and *Portheus* with the Elasmobranch *Corax*. Among reptiles the marine *Ichthyosaurus* and the Dinosaurian genera *Ornithopsis* and *Megalosaurus* survive from Jurassic time, but the Plesiosaurs are represented by *Cimoliosaurus* and *Polyptychodon*. Fresh Dinosaurs make their appearance, *e.g.* *Iguanodon*, *Hypsilophodon*, *Hylæosaurus*, *Polacanthus*, and *Vecti-*

saurus in the Lower Cretaceous, with *Acanthopholis*, *Anoplosaurus*, and others in the Upper Cretaceous. In the sea were large lizard-like reptiles of the order Squamata (*Coniosaurus*, *Mosasaurus*, and *Dolichosaurus*), and in the air the Pterosauria were represented by species of *Pteranodon* and *Ornithocheirus*.

Remains of birds also occur in the Upper Cretaceous Series, but only one genus has been found in Britain, the *Enaliornis* of the Cambridge Greensand. In America remains are more plentiful, and three remarkable genera have been described — *Hesperornis*,

Fig. 152.—RESTORED SKELETON OF HYPSILOPHODON FOXI ($\frac{1}{16}$), (after O. C. Marsh).
Length over 5 feet.

Ichthyornis, and *Apatornis*. *Hesperornis* was a large bird about 6 feet in length, and possessing many reptilian characters, so that it forms a link between the Jurassic *Archæopteryx* and more highly developed birds; its jaws were furnished with teeth planted in a long alveolar groove, its wings rudimentary, and its hind limbs strong, so that it was a wader and lived chiefly on fish. *Ichthyornis* and *Apatornis* were much smaller birds with well-developed wings, but both had reptilian skulls with teeth set in sockets, and their vertebræ were biconcave like those of Fish and Amphibians.

Mammalia also existed, though remains of them are very rare, and none have been found in England; they consist of teeth of

small Prototheria (*Cimolomys* and *Selenacodon*) related to the Jurassic *Plagiaulax*, and some bones of true Marsupials referred to the genera *Didelphops*, *Cimolestes*, and *Telacodon*.

The following are some of the more important marine genera which first appear in the Lower Cretaceous Series :—

<i>Porifera</i> .	Barroisia, Catagma.
<i>Actinozoa</i> .	Brachycyathus, Holocystis.
<i>Echinoderma</i> .	Cardiaster, Catopygus, Discoidea, Toxaster (= Echinospatagus), Enallaster, Goniopygus, Salenia.
<i>Crustacea</i> .	Hoplolaria, Meyeria, Mithracites.
<i>Brachiopoda</i> .	Kingena.
<i>Lamellibranchia</i> .	Crassatellites, Pectunculus, Cyprimeria, Cyclorisma, Monopleura, Requienia, Toucasia, Sphærolites, Thetironia (= Thetis).
<i>Gastropoda</i> .	Aporrhais (Ornithopus, Dimorphosoma), Avellana, Eulima.
<i>Cephalopoda</i> .	Desmoceras, Hoplites, Schœnbachia, Crioceras, Anisoceras, Macroscaphites, Hamulina.

The following are some of the more important genera which make their appearance in Upper Cretaceous time :—

<i>Porifera</i> .	Camerospongia, Cephalites, Chenendopora, Cœloptychium, Coscinopora, Doryderma, Guettardia, Hallirhoa, Leptophragma, Nematinion, Plinthosella, Pharetrospongia, Plocoscyphia, Siphonia, Stauro-nema, Ventriculites, Verruculina.
<i>Actinozoa</i> .	Caryophyllia, Cœlosmia, Cyclocyathus, Micrabacia, Onchotrochus, Parasmilia.
<i>Echinoderma</i> .	Caratodus, Cottaldia, Galerites (= Echinoconus), Echinocorys (= Ananchytes), Epiaster, Hemia-ster, Infulaster, Micraster, Bourgueticrinus, Marsupites.
<i>Crustacea</i> .	Etyus, Eucorystes, Neocarcinus, Palæocorystes, Palæga, Enoplocytha.
<i>Brachiopoda</i> .	Lyra (= Terebrirostra), Trigonosemus.
<i>Lamellibranchia</i> .	Hippurites, Radiolites.
<i>Gastropoda</i> .	Actæonella, Cassidaria, Columbina, Cominella, Crepidula, Fusus, Pugnellus, Volutospina.
<i>Cephalopoda</i> .	Acanthoceras, Buchiceras, Baculites, Heteroceras, Mammites, Pachydiscus, Placenticeras, Prionocyclus, Prionotropis, Scaphites, Turritites, Actinocamea, Belemnites.
<i>Pisces</i> .	Hoplopteryx, Corax, Macropoma, Osmeroides, Plethodus, Portheus, Ptychodus.
<i>Reptilia</i> .	Mosasaurus, Pteranodon, Ornithocheirus.

I. LOWER CRETACEOUS SERIES

As in the case of the Jurassic System it will simplify matters to describe the rocks and fossils of the Lower Series in England and Europe first, before dealing with those of the Upper Series.

Fig. 153.—FOSSILS OF THE WEALDEN BEDS.

A. *Onychiopsis* Mantelli.B. *Unio valdensis*. Fig. 154.—GROUP OF FOSSILS FROM THE SPEETON CLAY
(Hauterivian and Barremian).a. *Pecten cinctus*.
b. *Hoplitès speetonensis*.c. *Hoplitès regalis*.
d. *Crioceras Duvall*.

The outcrops of the Lower Series in England can be seen in any of the maps mentioned in Chapter III, p. 27, and the areas which they occupy in the western and central parts of Europe are shown on the larger geological maps of Europe. Those of the Cretaceous as a whole are indicated on the map specially prepared by Mr. Stanford for use with this volume (see p. 28).

A. LOWER CRETACEOUS LIFE

The following are some of the species which characterise the several stages of this series.

Marine Fauna.—As will be seen later on, the marine facies of Northern Europe, even where it is most complete, differs greatly from that of Central and Southern Europe, and very few fossils are common to the two faunas. We shall therefore in the first place give a list of the characteristic fossils of each of the stages as developed in France and Switzerland, together with those of the English Vectian. A further list of the chief members of the northern fauna will then be given.

Fossils of the Valcnginian

- Echinodermata.* Toxaster (Echinospatagus) Campichei, Pygurus rostratus.
Lamellibranchia. Ostrea rectangularis.
Gastropoda. Nerinae Meriani, Natica leviathan.
Cephalopoda. Hoplites neocomiensis, Hop. regalis, Hop. occitanicus, Hop. Boissieri, Phylloceras semisulcatum, Belemnites latus, Bel. dilatatus.

Fossils of the Hauterivian

- Echinodermata.* Toxaster complanatus, Holecypus macropygus.
Brachiopoda. Terebratula tamarindus, Rhynchonella lata.
Lamellibranchia. Neithea atava, Astarte numismalis, Ostrea Couloni.
Cephalopoda. Hoplites radiatus, Hop. leopoldinus, Hop. angulicostatus, Holcostephanus (Astieria) Astieri, Crioceras Duvali, Belemnites dilatatus.

Fossils of the Barremian

- Echinodermata.* Heteraster oblongus, Het. Couloni, Toxaster Collegnoi.
Brachiopoda. Rhynchonella Moutoni.
Lamellibranchia. Requinia ammonia, Toucasia Lonsdalei.
Gastropoda. Harpagodes Pelagi.
Cephalopoda. Holcostephanus fallax, Desmoceras difficile, Crioceras Emerici, Macroscaphites Yvani.

Fossils of the Aptian and Vectian

- Foraminifera.* Orbitolina lenticularis.
Echinodermata. Enallaster Tittoni, Peltastes Wrighti.
Crustacea. Meyeria magna (= vectensis).

Fig. 155.—GROUP OF VECTIAN FOSSILS.

1. <i>Corbis corrugata</i> .	4. <i>Astarte subcostata</i> .
2. <i>Trigonia caudata</i> .	5. <i>Arca aptiensis</i> .
3. <i>Gervillia anceps</i> .	6. <i>Perna Mulleti</i> .
7. <i>Cyclorisma parva</i> .	

- Brachiopoda.* Terebratula sella, T. depressa, Terebratella oblonga, Terebratella Filtoni, Rhynchonella Gibbsi.
- Lamellibranchia.* Exogyra sinuata (= Ostrea aquila), Toucasia caudata, Trigonia caudata, Trigonia nodosa (= Trigonia rudis), Perna Mulleti, Plicatula placunea, Arca aptiensis, Astarte subcostata, Gervillia anceps, Sphaera corrugata, Cyclorisma parva.
- Gasteropoda.* Dicroloma robinaldina, Aporrhais Fittoni.
- Cephalopoda.* Hoplites furcatus, Hop. Deshayesi, Douvilleiceras Martini, Macroscaphites gigas, Nautilus pseud-elegans.

Fig. 150.—GROUP OF VECTIAN FOSSILS.

- a. Macroscaphites gigas. c. Meyeria magna.
b. Hoplites Deshayesi. d. Terebratula sella.

The northern fauna includes the following characteristic species :—

Fossils of the Belemnites lateralis zone

- Lamellibranchia.* Astarte senecta, Trigonia ingens, Aucella volgensis, Aucella Keyserlingi.
- Cephalopoda.* Holcostephanus subditus, Holc. kashpuricus, Holc. plicomphalus, Hoplites regalis (= H. noricus), Hoplites amblygonius, Belemnites lateralis.

Fossils of the Bel. jaculum and Holc. Decheni Zone

- Crustacea.* Meyeria ornata.
- Lamellibranchia.* Pecten cinctus, Exogyra sinuata.

- Cephalopoda.* Holcostephanus (Astieria) Astieri, H. (Simbirskites)
Decheni, H. (Simbirskites) versicolor, Hoplites
speetonensis, Crioceras Duvali, Belemnites jaculum.

Fossils of the Hoplites Deshayesi zone

- Lamellibranchia.* Grammatodon securis, Corbula angulata, Nucula
subangulata.
Cephalopoda. Hoplites Deshayesi, Hoplites furcatus, Ancyloceras
gigas, Belemnites brunsvicensis, B. Jasekowi.

Lastly there is the freshwater facies of the English and German Wealden which represents the terrestrial and lacustrine life of the period.

Fossils of the Wealden Beds

- Plantæ.* Chara Knowltoni, Equisetites Lyelli. *Filices*: Onychiopsis
Mantelli, Matonidium Gœpperti, Cladophlebis Albertsi,
Sphenopteris Fittoni, Tempskya Schimper, Weichselia
Mantelli. *Cycadaceæ*: Cycadites Roëmeri, Dionites Dun-
kerianus, Nilssonina Schaumburgensis, Otozamites Klip-
steini, Zamites Buchianus, Anomozamites Lyellianus.
Coniferæ: Pinites Dunkeri, Sphenolepidium Kurrianum.
Crustacea. Cypridæa valdensis, Cythere Fittoni, Estheria elliptica.
Gastropoda. Viviparus fluviorum, V. cariniferus.
Lamellibranchia. Cyrena media, C. elongata, Unio valdensis, U. com-
pressus, U. aduncus.
Pisces. Lepidotus Fittoni, Hybodus dubius.
Reptilia. Iguanodon Mantelli, Hypsilophodon Foxi, Ceteosaurus
brevis, Hylæosaurus Oweni, Megalosaurus Bucklandi,
Goniopholis crassidens, Chelone Mantelli.

B. BRITISH REPRESENTATIVES

In England the Lower Cretaceous rocks occupy a much smaller surface-area than those of the Upper Series, but that is largely due to their overlap by the base of the Upper Series. The subterranean extension of the Lower Series is of importance, because the sands in its higher part are water-bearing, and borings have frequently been made in search of them. As a result of the borings already made, its subterranean extent in the east of England is now fairly well known; thus though these sands are present at Chatham they are absent at Streatham and also on the north side of the Thames beneath Middlesex, Essex, and the south of Suffolk. They were found, however, in borings near Windsor, at Hitchin, at Culford near Bury St. Edmunds, and recently at Lowestoft. Hence they probably underlie the whole of Cambridgeshire and Norfolk, and extend far under the North Sea east of Lincolnshire and Yorkshire.

Standard's Geography: Etc. b¹, London.

Fig. 157.

With regard to their western range, in all probability the Wealden and Vectian deposits did not extend much farther west than the most westerly portions of them now existing. In Dorset the Wealden extends to Upway near Weymouth, being there 350 feet thick, but is soon cut off by intra-Cretaceous erosion; the Vectian does not reach so far, but is cut off west of Mupe Bay; both, however, may originally have extended as far as Bridport. In the Vale of Wardour near Dinton the two are less than 100 feet thick, and cannot have reached much farther west along that line of latitude, for there the Vectian passes up into Gault.

Coming now to the surface exposures of the older Cretaceous Series, these are found in four separate districts—(1) The Wealden area, (2) The Isles of Wight and of Purbeck, (3) The Midland outcrop, a long narrow one, (4) the north-east area in Norfolk, Lincoln, and Yorkshire. The two southern areas may be described together as they exhibit a similar succession of deposits, and are undoubtedly connected beneath the Chalk of Hampshire.

1. *South of England*

The Weald is an oval-shaped area occupying portions of Kent, Surrey, Hants, and Sussex (see map, Fig. 157); on the north-west and south it is bounded by the escarpment of the Chalk, but eastward it opens on to the English Channel between Eastbourne and Folkestone. The district known as the Bas Boulonnais in France is the eastern prolongation and termination of the Wealden area, and the English and French districts are undoubtedly continuous beneath the English Channel. The structure of this area is generally described as that of an anticlinal ridge, but in reality it more resembles that of an oval dome or inverted boat.

Fig. 158 is a diagrammatic section across the Weald from north to south, showing its general structure and regarding only the Cretaceous rocks; Fig. 159 is a more complete and accurate section taken along a line drawn from Beachy Head to Chatham. The absence of the Lower Cretaceous below Chatham has been proved by a boring there, which entered the Oxford Clay directly below the Vectian sands, and this part of the section is reduced from that drawn by Mr. W. Whitaker.¹

In the Isle of Wight, and again in South Dorset, from Swanage to Ridgway near Weymouth, the Lower Cretaceous Series is brought to the surface by a sharp anticlinal curvature.

The following is a tabular view of the subdivisions which have been made in the series as developed in these two districts:—

Fig. 158.—GENERALISED SECTION ACROSS THE CENTRE OF THE WEALDEN AREA. Distance about 45 miles.

Fig. 159.—SECTION ACROSS THE WEALD OF KENT AND SUSSEX VIEWED FROM THE EAST. Distance about 50 miles.

- 9. Chalk (Lower, Middle, and Upper).
- 8. Selbornian (Gault and Upper Greensand).
- 7. Vectian (or Lower Greensand).
- 6. Weald Clay.
- 5. Hastings sands.
- 4. Purbeck Beds.
- 3. Portlandian and Kimmeridgian.
- 2. Corallian.
- 1. Oxfordian.
- P. Palaeozoic rocks.

	Weald.	Isle of Wight.	Thickness. Feet.
Vectian	Folkestone Beds	Carstone	160 to 200
	Sandgate Beds	Sand-rock Series	
	Hythe Beds	Ferruginous sands	280 to 520
	Atherfield Clay	Atherfield Clay	60 to 130
Wealden	Weald Clay	Weald Clay	up to 900
	Hastings sands	Not seen	up to 1000

Wealden Beds.—In the Wealden area the Wealden Beds are divisible as follows, all the divisions being thickest in the western and thinnest in the eastern part of the area.² Still farther east borings through the Chalk between Canterbury and Dover have shown that it gradually thins out; thus at Brabourne it is only about 56 feet, and in the Dover boring about 80 feet, while at Fredville it is less than 40 feet thick:—

		Feet.
Weald Clay		900 to 350
Hastings Sands	Tunbridge Sand	380 to 150
	Wadhurst Clay	160 to 100
	Ashdown Sand	500 to 200
		1940 to 800

The Ashdown Sand consists of soft buff or white sand and sandstone: it is 400 feet thick in Ashdown Forest, and forms the high ground of Crowborough Beacon (800 feet high). Near Hastings and Fairlight the lower part of this sand is replaced by clays with interbedded sandstones. Plant-remains are the only fossils, and it is the Fairlight Clay which has yielded the species mentioned on p. 471; the stems of *Tempskya*, formerly called *Endogenites erosa*, being common.

The Wadhurst Clay, though never more than 160 feet thick, is palæontologically important, as it is rich in fossils, and contains a bone-bed near Battle, from which many reptilian bones and teeth have been obtained. It consists of clays and shales, with bands of irregular layers of hard calcareous sandstone (Tilgate stone). The fossils are *Viviparus fluviorum*, *Cyrena media*, teeth of *Lepidotus Mantelli*, *Hybodus basanus*, *Goniopholis crassidens*, with bones of *Iguanodon* and *Megalosaurus*.

The Tunbridge Sands are similar to the Ashdown Sands. Near Hastings their thickness is only 150 feet, but it increases westward, a set of mottled clays and shales appearing in the middle of the sands, and becoming of sufficient importance to deserve a separate name, the Grinstead Clay. In the upper sands of the Cuckfield district, which is often called the Tilgate Forest, there are large concretionary masses of calcareous grit or sandstone, such as were termed Tilgate stone by Dr. Mantell. It was in these masses

that the remains of *Iguanodon* and *Hylaeosaurus* were first discovered by Dr. Mantell, and the specimens which he figured and described are now in the South Kensington Museum.

The uppermost member of the Wealden Group consists mainly of brown and blue clays, with layers of shelly limestone and occasional beds of sand and calcareous sandstone. The limestones are known as Sussex marbles, and are composed almost entirely of *Viviparus* shells, those in the lower part of the clay consisting chiefly of *V. sussexensis*, while the most constant band (the Petworth and Bithersden marbles) consists of *V. fluviorum*. The minute freshwater Crustaceans (*Cypridea*) are also very abundant in some places, the surfaces of the more shaly beds being crowded with them. *Unio* and *Cyrena* also occur. At Haslemere the highest beds, just below the Atherfield Clay, contain *Corbula* and *Mytilus*, as well as *Cyrena* and *Melanopsis*, indicating the change from freshwater to marine conditions.

In the Isle of Wight Wealden Beds are exposed both on the eastern and western sides (see map, Fig. 172). The equivalent of the Hastings sands is not visible; the lowest beds seen are those at Brook Point in Compton Bay, and consist of a pale sandstone overlain by red and green marls in which the broken trunks of pine trees are so numerous that it would seem as if a raft of waterlogged trees had here sunk to the bottom, a frequent occurrence in the deltas of large rivers like the Mississippi; the spot is known to local geologists as the "pine-raft." The higher beds, consisting of variegated marls or clays with thin beds of sandstone, can be seen by walking along the coast to the southward; they have yielded bones and footprints of *Iguanodon*, *Hypsilophodon*, and other reptiles, with *Unio valdensis*, but other fossils are rare in this lower division, which has a thickness of about 700 feet.

The higher beds are well exposed between Cowleaze Chine and Atherfield Point; they consist almost entirely of grey shales with some beds of sandstone, ironstone, and limestone. These beds are much more fossiliferous, containing species of *Meta*, *Cypris*, *Cypridea*, and *Candona*, with *Cyrena*, *Viviparus*, and *Vicarya* (a sub-genus of *Potamides*). Small oysters also occur near the top. This series of beds is about 200 feet thick, and is directly overlain by the "Perna Bed" mentioned below.

The whole of the Wealden comes to the surface near Swanage in Dorset, and extends thence along a broad valley to Worbarrow Bay on the other side of the Isle of Purbeck. At Swanage the estimated thickness of the formation is about 2300 feet,³ but the junction with the Purbeck is not exposed. The lower beds consist of variously coloured sands and clays—red, yellow, grey, and

white. The succeeding beds are red, purple, and white clays with beds of sand, and they contain layers of lignite and, in one place, the broken trunks of trees. At the top are shales (Pinfield Beds) like those of the Isle of Wight, but only 34 feet thick.

The greater part of the Wealden is exposed in the cliffs of Worbarrow Bay, but here its total thickness is reduced to about 1200 feet, and it consists entirely of alternating sands and clays with much lignite. The formation continues to diminish westward, and where last seen at Ridgway the thickness exposed is only 350 feet, but this may not be the full amount.

Wealden Clays are found over a small space in the Vale of Wardour, but are only 60 or 70 feet thick. Probably they do not extend much farther northward, but their boundary line is concealed beneath the Upper Cretaceous rocks.

Vectian.—In the Wealden district the lithological characters of the beds composing this stage are very variable, but four subdivisions are generally recognised (see p. 475 and Figs. 160, 161). Along the north side of the Weald the thickness of the Vectian varies from about 500 feet in Surrey to 240 near Sandgate, and about 130 in the boring at Dover.

The *Atherfield Beds* are exposed on the Kentish coast between Sandgate and Hythe, and are traceable thence all round the area occupied by the Weald Clay, except between Lewes and Eastbourne. In Surrey they are traversed by the railway cuttings at Sevenoaks and Red Hill, *Panopæa plicata*, *Exogyra sinuata*, *Perna Mulleti*, and *Trigonia dædalea* being common fossils; along this line their thickness varies from 30 to 50 feet. At Haslemere it is 60 feet, and their junction with the Wealden was observed by Mr. Salter, who says "the change from dark greyish-blue clay (Wealden) to the purely marine deposit of brown clay was marked no less by the fossils than by the change in the colour of the bed." Within a few inches of the Wealden Clay he found *Pleuromya plicata* abundantly embedded in the vertical position which such molluscs occupy when alive. This shows how quiet and gentle was the change from estuarine to marine conditions of deposit.

In the Isle of Wight the *Atherfield Clay* has at its base two beds which are together known as "Perna Bed," because *Perna Mulleti* is common in them and does not occur above. The lower bed consists of sandy clay with a thin basal seam of coarse grit containing rolled fragments of fossils and many broken bones and teeth of fish; this clay is $2\frac{1}{2}$ feet thick and is succeeded by a bed of brown calcareous sandstone also $2\frac{1}{2}$ feet. Both layers contain many fossils. The rest of the subdivision consists of pale blue clay with many flat calcareous concretions, and the upper part is

known as the "lobster bed," from the occurrence of *Meyeria magna*. Other fossils found in these beds are *Hoplites furcatus*, *Hop. leopoldinus*, *Hop. Deshayesi*, *Corbis corrugata*, *Pinna robinaldina*, and *Enallaster Fittoni*.

Hythe Beds.—In Kent, between Hythe and Sevenoaks, these beds consist of greenish-yellow sand, often marly or argillaceous, and hard bluish-grey calcareous sandstone, the soft beds being locally known as hassock and the hard beds as rag; the latter being known as Kentish rag. The beds of rag and hassock alternate in regular layers.

From Hythe to Maidstone the thickness of these beds is only from 70 to 80 feet, but they increase rapidly westward and are 160 feet at Sevenoaks, and still thicker in Surrey. This increase of thickness is mainly due to the incoming of an upper set of sands with frequent layers of brown chert. These upper beds

Fig. 160.—SECTION THROUGH THE LOWER CRETACEOUS SERIES NEAR DORKING.
Distance 8 miles.

8. Middle and Lower Chalk.	5. Folkestone Beds.	2. Atherfield Clay.
7. Malmstone and sand.	4. Sandgate Beds.	1. Wealden Beds.
6. Gault marls and clays.	3. Hythe Beds.	

attain their maximum thickness about Reigate, Dorking, and Leith Hill, where the lower group of soft ferruginous sand is from 100 to 130 feet, and the cherty beds are also in places over 100 feet thick. The Hythe Beds maintain this facies all round the western end of the Wealden area, but thin rapidly eastward again as they are traced along the southern border, disappearing entirely near Lewes.

The chief fossils of the Hythe Beds are *Terebratula sella*, *Exogyra sinuata*, *Trigonia spinosa*, *Tr. ornata*, *Actinocamax brunsvicensis*, *Nautilus pseudelegans*, *Ancyloceras Bowerbanki*, *Macroscaphites gigas*, *Hoplites Deshayesi*, and *Holcostephanus Hambrovi*.

Sandgate Beds.—These are a variable set of beds, but are generally more or less argillaceous. At and near Sandgate (see Fig. 161) they consist of dark-green clayey sand full of glauconite grains and about 70 feet thick. Fossils are not numerous, but at the base, resting on the Hythe Beds, there is frequently a layer of pebbles and phosphate nodules, with Brachiopods and other fossils in the state of casts.

In Surrey this division is represented by the Nutfield and Bargate Beds, which at Nutfield consist chiefly of soft sandstone and Fuller's Earth (a fine silty clay).⁴

Between Reigate and Godalming the Bargate Beds consist of sands and hard calcareous grits (Bargate stone), with some thin layers of Fuller's Earth and coarse pebbly beds at the base, containing phosphate nodules and many fossils; the whole thickness is about 50 feet. *Avicula pectinata* is a characteristic fossil of the Bargate stone; *Terebratula oblonga*, *T. depressa*, *Waldheimia tamarindus*, *Terebratella Fittoni*, *T. trifida*, and *T. Menardi* are some of the fossils occurring in the pebble beds, and with them are many fossils derived from the Oxford Clay, which must at that time have formed part of the shore-line north of Godalming.

In Hants and West Sussex the Sandgate Beds reappear in a more normal form, consisting of shaly clay at the top, with sand and sandy clay below.

In the Isle of Wight the Hythe and Sandgate Beds are represented by the *Ferruginous sands*, which consist of alternating beds of sand and clay, the sands of grey, green, or yellow tints and the clays brown or blue. The lowest beds are known as "the crackers," and contain *Holcostephanus Hambrovi*, *Gervillia anceps*, *Trigonia caudata*, *Pleuromya plicata*, etc. The overlying beds contain *Terebratula sella* in great profusion with *Douvilleiceras Martini*, *Macroscaphites gigas*, *M. Hillsi*, and *Crioceras Bowerbanki*. These lower beds may be called the Walpen sands, and they correspond to the Hythe Beds. Above them are the equivalents of the Sandgate Beds, comprising two beds or bands, the lower of sand with ferruginous concretions about 20 feet thick, the upper a bed of clay without fossils and 40 feet thick. The concretions yield *Rhynchonella sulcata*, *Avicula pectinata*, *Thetis Sowerbyi*, *Cyprina angulata*, and *Trigonia vectiana*.

Folkestone Beds.—At Folkestone these consist of light-green and grey sand with beds of hard stone, partly siliceous and partly calcareous in composition, which have been described by Dr. G. J. Hinde as veritable sponge-banks, the sponges being of the Hexactinellid order, and their fine needle-like spicules are clearly visible on weathered portions of the rock. The total thickness is about 80 feet. Fossils are not abundant in these beds, but they have yielded *Avicula pectinata*, *Exogyra sinuata*, *Pecten (Neithea) atava*, *Neithea Morrisi*, *Ostrea frons*, and *Waldheimia pseudojurensis*.

For a few miles inland the composition of the Folkestone Beds is much the same, but west of Saltwood they begin to change their character, the cherty sponge-beds disappear, and the sands are chiefly white, yellow, and brown, current-bedded, and including

Fig. 161.—SECTION THROUGH HYTHE AND FOLKESTONE. Distance about 6 miles.

Fig. 162.—SECTION THROUGH CAMBRIDGE AND THE GOG-MAGOG HILLS. Distance about 20 miles. Reduced from the Geological Survey section and reproduced from *Proc. Geol. Assoc.* vol. viii. p. 401.

irregular layers of ironstone. This facies they preserve with little change all round the Wealden area, and consequently the name of Folkestone Beds is not a very happy one. In Sussex they include thin bands of hard ferruginous grit, which is locally known as *carstone*. In Surrey and Hants they are from 130 to 160 feet thick, but like all other members of the Vectian, they thin eastward through Sussex, till near Eastbourne the whole stage appears to be absent, and the Gault rests directly on the Weald Clay.

The *Sand-rock Group* appears to be the representative of the Folkestone Beds. It consists mainly of coherent sands with bands of laminated clay, but contains no fossils. The carstone is a coarse ferruginous grit which varies greatly in thickness, being 72 feet thick at Redcliff, north of Sandown, but only from 6 to 12 feet on the western side of the island. It contains rolled pebbles and phosphatic nodules, and is considered by Mr. Strahan to be more closely connected with the Gault than with the Vectian.⁵ The fossils found in it comprise *Desmoceras Beudanti*, *Plicatula carteroniana*, and *Lima parallela*.

When followed across to Dorset the Vectian is found to be much reduced in thickness, being only 200 feet at Punfield Cove, near Swanage, 136 at Worbarrow Bay, and 66 in Mupe Bay, beyond which it is not seen. At Punfield the Atherfield Clay is 50 feet thick, and the upper part contains some remarkable fossils, especially species of *Vicarya*, *Natica*, *Actæon*, *Cerithium*, and *Pleurotoma*, which are common in the Rhodian of Spain, but have not been found elsewhere in England.

2. Midland District

The Wealden is not seen anywhere north of the Vale of Wardour, and the sands and sandstones which emerge from beneath the Gault in Berkshire, and thence at intervals northward to Cambridge and Ely, seem to belong to the higher part of the Vectian Group, nothing comparable to the Atherfield Clay or the Hythe Beds having been observed *in situ*.

Near Faringdon⁶ (see Fig. 163) the Vectian consists for the most part of soft yellow and brown sands, with some layers of sandstone and thin bands of ironstone, but at the base there are irregular beds of pebbly, fossiliferous gravel, compacted in places into a conglomerate. The pebbles are chiefly of quartz and porcellaneous slate (lydianite). Among the fossils sponges, Brachiopods, and Echinoids are conspicuous, the following being some of these :—

Terebratula tornacensis.
 " *depressa*.
Waldheimia tamarindus.

Peltastes Wrighti.
Cidaris faringdonensis.
Raphidonema porcatum.

Fig. 163.—SECTION FROM FARINGTON TO THE ESCARPMENT OF THE CHALK NEAR WHITE HORSE HILL (BERKSHIRE). Distance about 6 miles.

3. Kimeridge Clay.
2. Corallian Beds.
1. Oxford Clay.

5. Fine sands } Vegetian.
4. Conglomerate }

8. Middle Chalk.
7. Lower Chalk.
6. Selbornian.

Fig. 164.—SECTION THROUGH THE LOWER CRETACEOUS SERIES NEAR DONNINGTON (LINCOLNSHIRE). Distance about 3 miles.

By Mr. A. Strahan in *Proc. Geol. Assoc.*

7. Tealby Clay.
8. Spilsby Sandstone.
9. Kimeridge Clay.

4. Red Chalk (Selbornian).
5. Carstone.
6. Tealby Limestone.

1. Boulder-clay.
2. Glacial sands and gravel.
3. Lower Chalk.

Terebratella Menardi.
 „ *Fittoni.*
Rhynchonella latissima.

Raphidonema faringdonensis.
Trematocystia anastomosans.
Peronidella ramosa.

The summit of Shotover Hill, south-east of Oxford, consists of ferruginous sands with bands of ochre and cream-coloured loam, which contain remains of freshwater shells, *Unio*, *Cyrena*, and *Viviparus*. Similar beds occur at Wheatley, Brill, Crendon, and Thame, where they include beds of grey and lilac clay. At Crendon, *Pecten aptiensis* has been found in a layer of calcareous concretions which overlies the clays, and marine fossils have also been found at Stone near Aylesbury. Hence there can be little doubt that the Shotover Beds, which rest in some places on Portland, in others on the Purbeck Beds, are freshwater deposits of Aptian age. Their thickness is variable with a maximum of about 50 feet.⁷

Yellow and white sands emerge from beneath the Gault near Leighton Buzzard and form a range of hills by Woburn and Ampthill as far as the neighbourhood of Shefford. Near their base are beds of phosphatic nodules, which were worked near Brickhill, and include casts of fossils derived from the underlying Jurassic Clays, together with well-preserved contemporaneous fossils. Among the latter are *Terebratula sella*, *T. depressa*, *T. microtrema*, *T. moutoniana*, and others, *Terebratella Menardi*, *T. Fittoni*, *Waldheimia celtica*, *W. tamarindus*, and others, *Peltastes Wrighti*, and many of the Faringdon sponges.⁸

The sands above are dug for glass-making purposes, and are believed to be about 200 feet thick near Woburn; they also contain a band of Fuller's Earth, which has been worked for more than a century.

These Woburn sands, passing beneath the valley of the Ivel, become conspicuous again near Sandy and Potton, with the same nodule beds near the base, in which derived reptilian bones are very abundant; thence the sands run through Cambridgeshire to the Fens south of Ely, near Streatham and Upware.

At Upware in the Fens of Cambridgeshire are sands and silts with two nodule beds similar to those of Brickhill and Potton, but containing a still larger number and variety of fossils. The beds are banked against the Corallian limestones, are less than 12 feet thick, and are overlain by the Gault, so that they seem on the point of thinning out.

3. Northern District

This includes the Lower Cretaceous tracts in the counties of Norfolk, Lincoln, and York. Each of these exhibits a somewhat

different facies, the deposits in Norfolk being mainly sands, while those in Yorkshire are clays and those in Lincolnshire are sands, clays, and limestones. In the two latter counties we have a more complete succession of marine deposits of Lower Cretaceous age than is found in any other part of England, and our detailed knowledge of them is mainly due to the labours of Professor J. W. Judd and Mr. G. W. Lamplugh.⁹ Unfortunately the Norfolk outcrop is separated from that of Lincolnshire by the breadth of the Wash, and in Yorkshire the exposed areas near Speeton are very small, their southerly continuation being concealed beneath the overlap of the Upper Cretaceous (see map, Fig. 165). Consequently correlation is rendered difficult and entirely dependent on the discovery of fossils. The probable correlation is shown in the following table:—

Yorkshire.	Lincolnshire.	Norfolk.
Clays with <i>Belemnites brunsvicensis</i>	{ Carstone Tealby limestone and Roach ironstone Tealby clay Claxby ironstone Spilsby sandstone	Carstone.
Clays with <i>Act. jaculum</i>		Snettisham clay.
Clays with <i>Belemnites lateralis</i>		} Sandringham sands. (Absent).

It will be convenient to take Yorkshire first, and in that county the only good exposure is on the coast near Speeton Gap, and hence the whole series, which has a total thickness of about 330 feet, is sometimes termed the Speeton Clay.

The base of this clay is a layer of black phosphatic nodules embedded in stiff clay. The fossils are badly preserved, but among them Professor Pavlow identifies *Belemnites absolutus* with Ammonites resembling *Holcostephanus Panderi* and *Holc. scythicus*, species characteristic of beds in Russia which are regarded as Portlandian. It is a question, however, whether these fossils are contemporaneous or derived. This bed is succeeded by clays which contain *Belemnites lateralis*, *Holcostephanus subditus*, *Holc. Lamplughii*, *Hoplites amblygonus*, with *Exogyra Couloni* and *Astarte senecta*. These clays are about 35 feet thick and were considered to be of Purbeck age by Professor Pavlow, but the continental zone of *Hoplites Boissieri* with which he correlated part of these beds is now regarded as the base of the Valenginian, and the natural base of the Cretaceous System both in England and Germany is at the base of this zone of *Bel. lateralis*.

The overlying clays form the zone of *Actinocamax jaculum* and

Fig. 165.—MAP OF THE CRETACEOUS AREAS IN LINCOLNSHIRE AND YORKSHIRE.

By G. W. Lamplugh (from Quart. Journ. Geol. Soc. vol. lli. p. 187).

The outcrops of the Lower Cretaceous Series are indicated by horizontal lines, and show up darker than the other parts of the map.

are about 120 feet thick. They appear to be divisible into three sub-zones characterised by Ammonites which in succeeding order are *Hoplites regalis*, *Holcostephanus speetonensis*, and *Holc. Decheni*. Besides these *Crioceras Duvali*, *Pecten cinctus*, *Meyeria ornata*, and many other fossils occur. The whole of this zone appears to be older than the Atherfield Clay, and is therefore a marine representative of the Weald Clay.

The highest part of the Speeton Clay consists of grey and black pyritous clays containing *Belemnites brunsvicensis*, *Hoplites Deshayesi*, a large *Crioceras*, *Arca securis*, *Isocardia angulata*, and others. These beds are clearly equivalent to the Vectian of Southern England; their total thickness is more than 150 feet, and may be 180, and they are succeeded by gritty clays of Gault age containing *Belemnites minimus*.

In Lincolnshire the Lower Cretaceous Beds emerge from beneath the Upper near Caistor, and extend thence in a gradually widening strip to the neighbourhood of Spilsby and Candlesby at the southern end of the Lincolnshire Wolds. The succession of beds found in this district is shown in Fig. 164, and the full thickness does not exceed 200 feet.

The Spilsby sandstone has a bed of derived phosphatic nodules at the base resting on the Kimeridge Clay. Above are soft yellow and grey sands, including large masses or doggers of calcareous sandstone, which are rich in fossils and yield *Belemnites lateralis*, *Holcosteph. subditus*, *Holc. plicomphalus*, *Trigonia ingens*, *T. robinaldina*, etc. The Claxby and Hundesby ironstones also appear to belong to this zone, as they have yielded *Bel. lateralis*, *Holc. Beani*, *Holc. Gravesiformis*, *Astarte senecta*, *Trigonia ingens*, *Rhynchonella multiformis*, *Terebratula sella*.

The Tealby Clays are from 40 to 100 feet thick, and represent the zone of *Bel. jaculum*, yielding that fossil with *Hoplites speetonensis*, *Crioceras Duvali*, and *Perna Mulleti*. The Tealby limestone contains *Bel. brunsvicensis*, *Exogyra sinuata*, *Pecten cinctus*, and appears to pass southward into a ferruginous oolitic marl, locally called "roach." Above these calcareous beds is the carstone, which has not yet yielded any fossils except at its junction with the red chalk, where *Bel. minimus* and *Terebratula biplicata* occur.

In Norfolk the thickness of the series is rather less than in Lincolnshire. The Sandringham sands consist of light-coloured sands with some beds of brown flaggy sandstone in the upper part; they have not yielded determinable fossils, and are not like the Spilsby sands; hence it is more likely, as Mr. Lamplugh suggests, that they represent the Tealby Clay. The Snettisham Clay contains *Bel. brunsvicensis*, and appears to be the equivalent of the

Tealby limestone, but it is nowhere more than 20 feet thick and thins out southward.

The carstone of this country is a brown ferruginous grit, often cemented by oxide of iron into a sandstone capable of being used as a building stone. Its thickness is about 40 feet, and it is only at its base that fossils have been found. Some of these occur as phosphatic nodules which may or may not be derived, others occur in concretionary lumps of hard grit, and include *Douvilleiceras cornuelianus*, *Trigonia scapha*, *Perna Mulleti*, *Isocardia angulata*, and *Cardium subhillanum*—species which prove that this part of the carstone is of Aptian age and comparable with the Hythe Beds. Hence we may infer that the carstone of Lincolnshire is of the same age.

4. Scotland

Rocks of Lower Cretaceous age have been found in Caithness and Aberdeen. Those of Caithness occur at Leavad near Wick and appear to be *in situ*; the exposure showing 20 feet of yellow sand with doggers of hard calcareous sandstone, which have yielded species of *Craspedites*, *Desmoceras*, *Crioceras*, and *Hamites*.¹⁰ *Craspedites* suggests a low horizon in the series.

In Aberdeen near Cruden boulders of a glauconitic sandstone or gauze occur in boulder-clay and contain fossils which form a curious assemblage of Vectian and Selbornian species, but the presence of *Holc. speetonensis*, *Crioceras Duvali*, and *Trigonia vectiana* appears conclusive of their Vectian age.¹¹

C. CONTINENTAL REPRESENTATIVES

The Lower Cretaceous deposits of the European continent vary greatly in their lithic components, their thickness, and their fossil contents. They may be regarded as comprising three different facies of the series, (1) a southern deep-sea facies typically developed in the south-east of France (Dauphiné and Provence), (2) a central or intermediate facies found in the Jura and Switzerland, (3) a northern facies found in Germany and Russia. It will suffice to describe the typical succession in each of these regions.

1. Provence

The finest sections in this area are those of the Montagne de Lure and Mount Ventoux near Sisteron and Simiane. The most recent studies of the strata forming these mountains are those of MM. Kilian and Leonhardt, and I shall here follow the capable

guidance of Professor Kilian with regard to the succession and the grouping of the zones.¹² The illustration, Fig. 166, is reproduced from one of his sections.

In this part of France there is a complete passage from the marine (Tithonian) facies of the Jurassic to the Lower Cretaceous, and the exact line of separation has been a matter of dispute, but Professor Kilian has made it clear that the zone of *Hoplites Boissieri* should be regarded as the first term in the Cretaceous Series. The thickness of the several stages varies considerably in different parts of the area, but the total is about 2000 feet, and as it largely consists of limestones its formation must have occupied a long period of time.

The following is a tabular view of the succession in the M. de Lure:—

Aptian, 300 to 600	{	Marls with <i>Belemnites semicanalicutus</i> , <i>Oppelia nesus</i> , and <i>Hoplites furcatus</i> .
		Limestone of Graves with <i>Toxaster Collegnoi</i> , etc.
Barremian, 200 to 400	{	Limestones with <i>Hoplites Deshayesi</i> passing into <i>Orbitolina</i> limestone with <i>Requienia ammonina</i> .
		Limestones with <i>recticostatus</i> and <i>Macroscaphites Yvoni</i> .
Hauterivian, about 300	{	Limestones with <i>Holcodiscus fullax</i> and <i>Crioceras Emerici</i> .
		Limestones with <i>Hoplites angulicostatus</i> .
Valenginian, 600 to 1200	{	Limestones with <i>Crioceras Duvati</i> , <i>Hoplites radiatus</i> , and <i>Bel. dilatatus</i> .
		Marly limestone with <i>Hoplites neocomiensis</i> and <i>H. regalis</i> .
		Marls with <i>Hoplites neocomiensis</i> and <i>Belemnites Emerici</i> . Marls with <i>Hoplites Boissieri</i> , <i>H. occitanicus</i> , and <i>Phylloceras semisulcatum</i> .

The limestone with *Requienia ammonina*, classed above as Aptian, is part of the special facies developed at Orgon in Vancluse, which was formerly regarded as the type of a stage called *Urgonian* by d'Orbigny but since found to pass laterally into Barremian and Lower Aptian.

2. The Jura

In this area the whole Lower Cretaceous Series is still purely marine, but the thickness is much less, being only from 500 to 700 feet, and Ammonoids are much less common than they are in the southern region, so that the same zones cannot be recognised. According to the most recent authorities the following is the general succession in the Eastern Jura and in the basin of the Rhone.

Aptian, 40 to 60	{	Marls with <i>Ostrea aquila</i> and <i>Plicatula placinea</i> represented at Perte du Rhone by sandstones, underlain by marls with <i>Orbitolina lenticularis</i> .
		White limestone with <i>Requienia ammonina</i> represented at Perte du Rhone by red and grey limestones with <i>Heteraster oblongus</i> and <i>Het. Couloni</i> .
Barremian, 100 feet	{	

Hauterivian, about 300 feet	{	Yellow limestone of Neuchâtel with <i>Toxaster complanatus</i> , <i>Terebratula tamarindus</i> , and <i>Rhynchonella lata</i> .
		Marls of Hauterive with <i>Hoplites radiatus</i> , <i>H. leopoldinus</i> , <i>Holc. (Astieria) Astieri</i> , and <i>Belemnites dilatatus</i> .
		Marls with Bryozoa and <i>Ostrea Couloni</i> .
Valenginian, 200 feet	{	Red oolitic limestone with <i>Pygurus rostratus</i> .
		White limestone with <i>Natica leviathan</i> .
		Marl and rubbly limestone with <i>Toxaster Campichei</i> .

3. Germany

The northern facies is well developed though not well exposed in Hanover. In the northern part of the province there appears to be a nearly complete marine series comparable with that of Speeton, and according to the recent observations of von Koenen the descending succession can be made out as follows:—

- 4 { Marls with *Hoplites furcatus* and *Belemnites brunsvicensis*.
Clay with *Hoplites Dschajesi*.
Clay with *Ancyloceras gigas* and *Belemnites Grasi*.
- 3 { Clays with several species of *Crioceras* and *Ancyloceras* with
Belemnites brunsvicensis.
- 2 { Clays with *Crioceras Tombecki* and *C. capricornus*.
Clays with *Hoplites radiatus* (= *noricus*).
- 1 { Clays with *Polyptychites tercissus* and *P. psilostomus*.
Clays with *Belemnites lateralis* and *Orynoticeras Gevrii*.

The figures 1 to 4 indicate a grouping which roughly corresponds with the Swiss and Jura stages, but the lowest marine clays are not probably equivalents of the lowest Valenginian, for in Southern Hanover the marine beds are underlain by a thick estuarine and freshwater formation comparable with the English Wealden and like it consisting of sandstones in the lower part and of clays in the upper part, containing *Corbula inflexa*, *Melania strombiformis*, *Cyrena*, and *Viviparus*. In some places these clays have been observed to alternate with the lower marine clays, and the German Wealden is probably a delta formation formed by a river discharging into the Northern Sea.

4. Russia

The corresponding series in Russia is best exposed on the right bank of the Volga between Simbirsk and Syrzan, but its total thickness is very small, being only from 50 to 60 feet, and it must therefore be regarded as a condensed representative. The divisions recognised by Professor Pavlow and other Russian geologists are:—

	Feet
7. Shales with <i>Hoplites Deshayesi</i>	17
6. Black clay with <i>Holcostephanus (Simbirskites) Decheni</i>	16
5. Black clay with <i>Holc. (Simbirskites) versicolor</i>	
4. Sand and phosphatic nodules, <i>Holc. Keyserlingi</i>	5
3. Calcareous sandstone of Riasan	3
2. Sands and phosphate nodules with <i>Hoplites nodiger</i> and <i>Hop. kashpuricus</i>	12
1. Sands with <i>Craspedites subditus</i>	10

The four lower zones contain *Belemnites lateralis* and the two upper *Bel. Jaskowi*, neither *B. jaculum* nor *B. brunsvicensis* occurring in Russia.

II. UPPER CRETACEOUS SERIES

A. STAGES AND ZONES

As stated on p. 471, the members of this series have a far wider extension than those of the lower series; they extend southward below the English Channel into France, they pass eastward beneath the eastern counties of England, and below the floor of the North Sea into Belgium and Holland. The following is a tabular view of the stages and zones into which the English Series is divisible, with the names of the corresponding French stages:—

Stages.	Zones.	French Divisions.
Upper Chalk	<i>Ostrea lunata</i>	Campanian.
	<i>Belemnitella mucronata</i>	
	<i>Actinocamax quadratus</i>	
	<i>Marsupites testudinarius</i>	Senonian.
	<i>Micraster coranguinum</i>	
	<i>Micraster cortestudinarium</i>	
Middle Chalk	<i>Holaster planns</i>	Turonian.
	<i>Terebratulina lata</i>	
Lower Chalk	<i>Rhynchonella Cuvieri</i>	Cenomanian.
	<i>Holaster subglobosus</i>	
	<i>Schlenbachia varians</i>	
Selbornian	<i>Pecten asper</i>	Albian.
	<i>Schlenbachia rostrata</i>	
	<i>Hoplites interruptus</i>	
	<i>Douvilleiceras mammillatum</i>	

B. CHARACTERISTIC FOSSILS

The following are some of the species which are characteristic of each of the four stages or subdivisions of the Upper Cretaceous series:—

*Fossils of the Selbornian and Albian**Porifera.*

Chenendopora Michelini, *Doryderma Benettii*, *Siphonia tulipa*, *Barroisia Orbignyi*.

Hydrozoa.

Parkeria sphaerica.

Fig. 167.—GROUP OF SELBORNIAN FOSSILS (GAULT).

a. <i>Trochocyathus conulus</i> .	f. <i>Bellerophina minuta</i> .
b. <i>Inoceramus sulcatus</i> .	g. <i>Hoplites splendens</i> .
c. <i>Plicatula gurgitis</i> .	h. <i>Hamites attenuatus</i> .
d. <i>Aporrhais carinata</i> .	i. <i>Nucula pectinata</i> .
e. <i>Scalaria gaultina</i> .	k. <i>Natica gaultina</i> .
	l. <i>Lima parallela</i> .

Actinozoa.

Cyclocyathus Fittoni, *Trochocyathus conulus*.

Echinodermata.

Cardiaster fossarius, *Cidaris gaultina*, *Echinospatagus murchisonianus*, *Cottaldia Benettii*, *Pentacrinus Fittoni*.

- Annelida.* *Serpula concava*, *Ditrupa difformis*.
Crustacea. *Etyus Martini*, *Necrocarcinus Beebei*, *Palaeocorystes Stokesi*, *Hoploparia longimana*.
Brachiopoda. *Terebratula biplicata*, *Terebratella pectita*, *Rhynchonella dimidiata*, *Lingula subovalis*.
Lamellibranchia. *Grammatodon carinatus*, *Cucullæa glabra*, *Pectunculus nmbonatus*, *Ostrea vesiculosa*, *Exogyra conica*, *Plicatula gurgitis* (= *P. pectinoides*), *Lina gaultina*,

Fig. 168.—GROUP OF SELBORNIAN FOSSILS (GREENSAND).

- a.* *Chenendopora expansa*. *d.* *Terebratula biplicata*.
b. *Micrabacia coronula*. *e.* *Exogyra columba*.
c. *Cottaldia Benettiae*. *f.* *Pectunculus sublevis*.
g. *Hoplites auritus*.

- Gastropoda.* *Inoceramus sulcatus*, *I. concentricus*, *Nucula pectinata*, *Panopea mandibula*, *Trigonia aliformis*.
Scaphopoda. *Dicroloma (Anechura) carinata*, *D. (Perissoptera) Parkinsoni*, *Solarium ornatum*, *Bellerophina minuta*, *Natica gaultina*, *Scalaria gaultina*, *Turritella granulata*.
Cephalopoda. *Dentalium decussatum*.
Douvilleiceras mammillatum, *Desmoceras Bendanti*, *Hoplites interruptus*, *Hoplites lautus*, *Hoplites splendens*, *Hoplites auritus*, *Schlenbachia rostrata*, *Schlenbachia variegata*, *Hamites attenuatus*, *Nautilus clementinus*, *Belemnites minimus*.

The following are common species which occur both in the Selbornian and the Lower Chalk (Cenomanian):—

Elasmostoma consobrinum, *Catopygus columbarius*, *Holaster laevis*, *Salenia petalifera*, *Pelastres clathratus*, *Pseudodiadema variolare*, *Ps. ornatum*, *Discoidea subuculus*, *Kiøgenia lima*, *Rhynchonella grasiana*, *Lima globosa*, *Pecten asper*, *P. orbicularis*, *P. hispidus*, *Ostrea vesicularis*, *Aucellina gryphaoides*, *Nautilus elegans*.

Fig. 169.—GROUP OF SELBORNIAN FOSSILS (GREENSANDS).

a. <i>Nautilus elegans</i> .	c. <i>Pecten asper</i> (young).
b. <i>Salenia petalifera</i> .	d. <i>Rhynchonella dimidiata</i> .
e. <i>Siphonia pyramidalis</i> .	

Fossils of the Lower Chalk and Cenomanian

<i>Porifera</i> .	<i>Stauronema Carteri</i> , <i>Plocoscyphia labrosa</i> , <i>P. fenestralis</i> .
<i>Actinozoa</i> .	<i>Micrabacia coronua</i> .
<i>Echinodermata</i> .	<i>Discoidea cylindrica</i> , <i>Holaster subglobosus</i> , <i>H. trecensis</i> , <i>Cidaris vesiculosa</i> .
<i>Annelida</i> .	<i>Serpula umbonata</i> , <i>S. annulata</i> .
<i>Crustacea</i> .	<i>Enoplocyrtia brevimana</i> .
<i>Brachiopoda</i> .	<i>Rhynchonella Martini</i> , <i>R. Mantelliana</i> , <i>Terebratulina semiglobosa</i> , <i>Terebratulina nodulosa</i> .
<i>Lamellibranchia</i> .	<i>Cucullæa mailleana</i> , <i>Inoceramus Crippsi</i> , <i>Lima aspera</i> , <i>Pecten elongatus</i> , <i>P. fissicosta</i> , <i>Plicatula inflata</i> , <i>Spondylus striatus</i> , <i>Unicardium ringmeriense</i> .

- Gastropoda.* Dieroloma (Perissoptera) Mantelli, Avellana cassis, Solarium bicarinatum.
Scaphopoda. Dentalium majus.
Cephalopoda. Schlenbachia varians, Acanthoceras rotomagensis, Acanthoceras Mantelli, Turritiles costatus, Scaphites æqualis, Baculites baculoides, Actinocamax plenus.

Fossils of the Middle Chalk

- Echinodermata.* Galerites (= Echinoconus) subrotundus, Cardiaster pygmæa, Discoida Dixoni, Cidaris hirudo.

Fig. 170.—GROUP OF LOWER AND MIDDLE CHALK FOSSILS.

a. Holaster subglobosus, $\frac{1}{2}$.	e. Rhynchonella Cuvieri, nat. size.
b. Turritiles costatus, $\frac{1}{2}$.	f. " Mantelliana, $\frac{1}{2}$.
c. Inoceramus labiatus, $\frac{1}{2}$.	g. Actinocamax plenus, $\frac{1}{2}$.
d. Schlenbachia varians, $\frac{1}{2}$.	h. Scaphites æqualis, $\frac{1}{2}$.

- Brachiopoda.* Terebratula semiglobosa, Rhynchonella Cuvieri, Terebratulina lata (= gracilis of most authors).
Lamellibranchia. Inoceramus labiatus (mytiloides), I. Lamarchi var. Cuvieri.
Cephalopoda. Maumites nodosoides, Pachydiscus peramplus, Prionotropis Woolgari.

Fossils of the Upper Chalk (lower zones)

- Porifera.* Camerospongia campanulata, Doryderma ramosum, Ventriculites impressus, V. mammillaris.

Fig. 171.—GROUP OF UPPER CHALK FOSSILS.

a.	<i>Belemnitella mucronata.</i>	f.	<i>Marsupites testudinarius.</i>
b.	<i>Terebratula carnea.</i>	g.	<i>Micraster coranguinum.</i>
c.	<i>Spondylus spinosus.</i>	h.	Leskei (base).
d.	<i>Galerites conicus.</i>	i.	præcursor (base).
e.	<i>Echinocorys vulgaris.</i>	k.	coranguinum (base).

- Echinoderma.* *Cidaris clavigera*, *C. perornata*, *Phymosoma* (= *Cyphosoma*) *radiatum*, *Holaster planus*, *Micraster Leskei* (= *breviporus*), *M. præcursor*, *M. cortestudinarium*, *M. coranguinum*, *Epiaster gibbus*.
- Lamellibranchia.* *Inoceramus involutus*, *I. Lamarcki*, and var. *Brongniarti*, *Lima Hoperi*, *L. divaricata*, *Plicatula Barroisi*.
- Gastropoda.* *Solariella gemmata*, *Trochus Schlüteri*, *Cerithium Saundersi*.
- Cephalopoda.* *Heteroceras reussianum*, *Scaphites Geinitzi*, *Baculites bohemicus*.
- Fossils of the Upper Chalk (higher zones)*
- Porifera.* *Cœloptychium agaricioides*, *Plinthosella squamosa*, *Scytalia radiciiformis*, *Siphonia Kœnigi*, *Stichophyma tumidum*.
- Anthozoa.* *Caryophyllia cylindræa*, *Cœlosmilia laxa*, *Parasmilia Fittoni*.
- Echinoderma.* *Galerites* (= *Echinoconus*) *abbreviatus*, *Offaster pilula*, *Marsupites testudinarius*, *Micraster coranguinum*, *Cardiaster ananchytis*.
- Brachiopoda.* *Rhynchonella limbata*, *Magas pumilus*, *Crania costata*, *Terebratulina Roweï*, *T. gracilis*.
- Lamellibranchia.* *Ostrea acutirostris*, *O. curvirostris*, *O. lunata*, *O. wegmaniana*, *Pecten Nilssoni*, *P. cretosus*, *P. Mantellianus*, *Spondylus dutempleanus*.
- Cephalopoda.* *Haploceras leptophyllum*, *Scaphites constrictus*, *Baculites Faujasi*, *Hamites cylindræus*, *Actinocamax quadratus*, *Act. granulatus*, *Belemnitella mucronata*, *B. lanceolata*.

Besides the above, the following are more or less common throughout the Upper Chalk :—

- Porifera.* *Heterostinia obliqua*, *Ventriculites decurrens*, *V. radiatus*.
- Anthozoa.* *Parasmilia centralis*, *Axogaster cretacea*.
- Echinoderma.* *Echinocorys* (= *Ananchytes*) *vulgaris*, *Galerites* (*Echinoconus*) *conicus*, *Cidaris sceptrifera*, *Phymosoma* (= *Cyphosoma*) *Kœnigi*.
- Brachiopoda.* *Terebratula carnea*, *Rhynchonella plicatilis*, *Rh. reedensis*.
- Lamellibranchia.* *Ostrea semiplana*, *Spondylus spinosus*.

C. THE UPPER CRETACEOUS OF BRITAIN

1. England

In describing the Upper Cretaceous strata it will be more convenient to take each stage separately and trace its variations across England.

Selbornian.—This stage includes the deposits which have long been known as Gault and Upper Greensand, names which date from a time when a Middle Cretaceous Series was supposed to exist, comprising the Lower Greensand, the Gault, and the Upper Green-

sand, which were supposed to occur in regular upward succession. As the palæontology of these deposits was more carefully studied it was seen that the "Lower Greensand" was a distinct stage, but that the Upper Greensand was inseparable from the Gault, and was to a large extent merely a sandy facies of the Gault. Hence it became necessary to combine these two facies under one name as a single stage. For this the name *Selbornian* has been chosen from the village of Selborne in Hampshire, though the names Gault and Greensand are convenient terms for the argillaceous and the sandy facies respectively.¹³ Where the stage is complete four zones can be distinguished. These are :—

4. Zone of *Pecten asper* and *Cardiaster fossarius*.
3. Zone of *Schlenbachia rostrata* (= *inflata*).
2. Zone of *Hoplites lautus* and *H. interruptus*.
1. Zone of *Douvilleiceras mammillatum*.

Of these zones the lowest is always a sand, the second is generally clay (*i.e.* Gault), the third may be clay or marl or malmstone or sand, the fourth is always a "greensand" or sandstone.

The typical development of the argillaceous facies is in Kent, and the beds are well exposed at Folkestone, where the "Lower Gault" consists of grey clays with several bands of phosphatic nodules and a layer of such nodules at the base embedded in dark-green glauconitic sand. The characteristic fossils are *Hoplites interruptus*, *H. splendens*, *H. lautus* (upper part), *Lima parallela*, *Pinna tetragona*, *Inoceramus concentricus*. Below and forming the base of the stage are 5 or 6 feet of coarse green sand containing *Douvilleiceras mammillatus*.

The Upper Gault or zone of *Sch. rostrata* consists of pale-grey marly clay about 78 feet thick; this includes a bed of dark-green glauconitic sand in the upper part, and is separated from the Lower Gault by a layer of phosphatic nodules. These beds yield *Schlenbachia rostrata*, *Sch. Goodhalli*, *Pecten raulinianus*, *Terebratula biplicata* in the upper part, *Schlenbachia varicosa* and *Inoceramus sulcatus* in the lower part.

Inland the thickness of the Gault becomes much greater and is about 200 feet near Maidstone. This increase appears to be chiefly in the Upper Gault, but it is not till we reach Westerham that the so-called "Upper Greensand" makes its appearance at the top of the Gault, and thence it thickens westward through Surrey. This deposit is known in Surrey as "firestone" and "hearthstone," and in Hampshire as "malmstone"; it is a greenish-grey siliceous stone consisting partly of fine sand and glauconite grains, partly of sponge spicules and globular colloid silica, and it passes down into sandy marls which are clearly part of the Upper Gault.

In Hampshire, near Alton and Selborne (see map, Fig. 157), the general succession is as follows :—

	Feet.
5. Soft greenish sands without fossils . . .	2 to 15
4. Malmstone with beds of calcareous stone . . .	80 to 100
3. Sandy marls with <i>Sch. rostrata</i> and <i>Inoc. sulcatus</i> . . .	30 to 50
2. Dark clays with <i>Hoplites interruptus</i> . . .	about 100
1. Green sands with phosphatic nodules . . .	3 to 15
	<hr/> About 240

From the malmstone *Schlenbachia rostrata*, *Hoplites auritus*, *Anisoceras armatum*, *Arca carinata*, and *Pleuromya mandibula* have been obtained, and there is no doubt that it represents the greater part of the Upper Gault of Folkestone.

In Wiltshire and the Isle of Wight there is a similar succession, and the beds are well exposed in the Undercliff along the south side of the Isle of Wight, where the following are the main subdivisions :—

	Feet.
<i>P. asper</i> zone—Sands and chert-beds (few fossils) . . .	about 30
<i>Sch. rostrata</i> { Soft sandstones and sandy malm . . .	„ 70
zone { Dark-grey sandy clays . . .	„ 45
Lower Gault—Blue clays with <i>Hoplites denarius</i> , etc. . .	„ 100

The “Gault” passes down into the “Carstone” (see p. 481), which Mr. A. Strahan is inclined to regard as representing the zone of *Douv. mammillatum*; but that fossil has not yet been found, and the question remains undecided.

In South Dorset the succession is similar, but the base of the Selbornian is sharply defined by a thin layer of quartz pebbles, while the Lower Gault becomes more and more sandy as it is traced westward. The zone of *Sch. rostrata* consists of green sands with beds of calcareous sandstone, and there is always a well-marked zone of *Pecten asper* at the top.

In Devon the beds are well exposed in the cliffs between Lyme Regis and Sidmouth, the base of the Selbornian gradually passing over the Lower Lias and across the Kenper marls till it rests on the Keuper sandstones (see Fig. 131, p. 396). At the base near Lyme and Axmouth there are still some few feet of clay (Lower Gault), but westward this either thins out or passes into sand. At Beer and near Beer Head the succession is as follows :—

	Feet.
Zone of { Hard calcareous sandstone (few fossils) . . .	about 10
<i>P. asper</i> { Sandstones with chert-nodules, <i>Exogyra digitata</i> . . .	60
Zone of { Soft grey sands passing down into dark-green	
<i>S. rostrata</i> { clayey sand, <i>Dosiniopsis caperata</i> . . .	90
	<hr/> 160

In this area *Pecten asper* does not occur in the Selbornian, but is found in the overlying arenaceous representative of the Lower Chalk.

At Sidmouth and in the Blackdown Hills the lower sands have yielded a rich fauna, the shells being preserved in chalcedony, and the following are some of the commonest species, *Sch. varicosa*, *Aporrhais calcarata*, *Turritella granulata*, *Protocardia hillana*, *Cucullæa glabra*, *Cytherea* (*Callista*) *plana*, *Dosiniopsis caperata*, *Lucina orbicularis*, *Trigonia aliformis*, and *Tr. scabricola*.

An outlier of the Selbornian sands occurs on the Haldon Hills about 12 miles south-west of Sidmouth. Here they rest on the red Permian breccias, and are reduced to a thickness of 70 or 80 feet.

Passing now to the main outcrop of the Selbornian from Wiltshire northward, we may briefly indicate the lithological variations which it exhibits in that direction. In Berkshire and Oxfordshire the facies is similar to that of Hampshire, but the total thickness is greater, being about 300 feet. The zone of *Sch. rostrata* is partly represented by marls and partly by malmstones, and the bed of unfossiliferous greensand at the top is a continuous band 15 or 20 feet thick. But both the greensand and the malmstone die out in Buckingham, leaving a purely argillaceous facies like that of Folkestone, the Lower Gault being about 150 feet thick and the Upper about 80 feet, a notable fact being the occurrence of a layer of phosphatic nodules at the base of the Upper Gault, embedded in glauconitic clay and lying on an eroded surface of the lower clays.

Traced to the north-east both subdivisions become thinner and the Upper Gault has also suffered erosion, with the result that a layer of nodules and fossils derived from it occurs at the base of the Lower Chalk. Near Cambridge the Gault is from 140 to 120 feet thick, including a variable thickness of the *rostrata* zone, but at Soham, where it passes below the level of the Fenland, it is only 90 feet.

When it emerges at Stoke Ferry in Norfolk it is still 60 feet thick, but at Roydon and Grimston it is less than 20 feet and consists of red and grey marls with two beds of grey limestone.¹⁴ Farther north it passes into a red limestone, which is generally called the "Red Chalk" and is so strikingly exposed in the cliffs at Hunstanton. This red rock is only $3\frac{1}{2}$ feet thick, and consists of three layers, each passing into the other. The lowest is sandy and of a deep brick-red colour full of *Bel. minimus* and *Terebratula biplicata*; the central part is a red nodular limestone with the same fossils and many others, including *Hoplites lautus*, *H. splendens*, *H. tuberculatus*, *Inoceramus sulcatus*, and *Inoc. concentricus*.

The highest layer is a pale-pink limestone with few fossils. Thus the Red Chalk appears to be a condensed representative of the whole Selbornian stage.

It appears again near Welton and Willoughby in Lincolnshire, where it is 10 to 12 feet thick, but thins again to 4 or 5 near Caistor. In South Yorkshire the beds are about 7 feet thick, thinning to the north-east, till at Leavening and Wharram it is less than 2 feet, its base containing pebbles of quartz and ironstone. Eastward, however, it expands, and at Speeton it is represented by over 30 feet of material as below:—

	Feet.
Smooth and firm red marl	about 4
Red marl, enclosing lumps of harder and more calcareous material, with many fossils	„ 16
Tough red marly chalk in irregular beds	„ 10
Red, yellow, and green clays, shaly and gritty	„ 1½

The lowest beds contain *Bel. minimus* and *Inoceramus sulcatus*, the higher hold *Terebratula biplicata*, *T. capillata*, *Kingena lima*, etc.

Lower Chalk.—This stage as developed in the south of England is divisible into two parts or zones, the lower part forming the zone of *Schænbachia varians*, and the higher part that of *Holaster subglobosus*. At the base, and included in the range of *Sch. varians*, is the sub-zone of *Stauronema Carteri*, consisting of sandy glauconitic chalk which is often called the “Chloritic marl.” At the top is a band of soft grey marl which is the sub-zone of *Actinocamax plenus*, often called Belemnite marl from the presence of that Belemnoid.

At Folkestone the beds composing the Lower Chalk are:—¹⁵

	Feet.
Zone of <i>Hol. subglobosus</i> , { 7. Belemnite marl (with <i>Act. plenus</i>)	6
126 feet { 6. Whitish chalk in massive beds (few fossils)	60
{ 5. Grey chalk in massive beds	60
{ 4. Grey marly chalk	20
Zone of <i>Sch. varians</i> , { 3. Alternating beds of grey marl and hard grey chalk with many fossils	22
68 feet { 2. Grey chalk with reefs of sponges (<i>Plocoscyphia</i>)	10
{ 1. Soft green glauconitic chalk (<i>Stauronema</i>)	16

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The Lower Chalk attains its greatest thickness in Wiltshire, where it is about 250 feet, the greater part belonging to the zone of *Sch. varians*, which includes beds of a peculiar siliceous chalk containing imperfect flints.

In the Isle of Wight the best exposure of the Lower Chalk is in the Culver Cliffs north of Sandown (see map, Fig. 172), where

Fig. 172.—GEOLOGICAL MAP OF THE ISLE OF WIGHT.

the total thickness is 212 feet, the zone of *Hol. subglobosus* with the Belemnite marl being 92 feet and the zone of *Sch. varians* about 120 feet. The basement bed or Chloritic marl is from 6 to 8 feet thick along the Undercliff (Ventnor, etc.), and abounds in phosphatised casts of *Schlenbachia varians*, *Acanth. Mantelli*, *Turrilites Morrisi*, and *Cucullæa mailleana*, together with shells of *Pecten asper*, *Rhynchonella grasiana*, and *Stauronema Carteri*.

In Dorset there is a more decided break between the Selbornian and the Lower Chalk; the basement bed is a glauconitic chalk with phosphatic nodules and fossils, but it does not seem to be the equivalent of the Chloritic marl, for it does not contain *Stauronema*, while it has other fossils which in the Isle of Wight are common from 10 to 20 feet above the Chloritic marl, such as *Scaphites æqualis*, *Acanthoceras rotomagensis*, *Turrilites Wiesti*, and *Holaster subglobosus*. Other common fossils are *Cucullæa mailleana*, *Unicardium ringmeriense*, and *Galerites castanea*. The thickness of the Lower Chalk is also less (140 feet near Swanage), diminishing westward till it is only about 60 feet in West Dorset.

The Dorset facies of the Lower Chalk can be traced inland by Bridport, Beaminster, and Crewkerne to Chard in Somerset, where it is still about 60 feet thick with a highly fossiliferous bed at the base; but when it reappears on the coast near Lyme and Seaton it has undergone such a change that it ceases to be chalk, and is reduced to a thin band of calcareous sandstone enclosing large grains of quartz. Near Lyme this bed is only 3 or 4 feet thick, but at Beer Head it swells out into two beds which have a combined thickness of 18 feet and are highly fossiliferous.¹⁶

The fossils in these calcareous sandstones show that they represent the Chalk marl of more eastern counties, the commonest being *Sch. varians*, *Acanth. Mantelli*, *Turr. costatus*, *Scaphites æqualis*, *Holaster subglobosus*, *Hol. lævis*, and *Galerites castanea*, while species which connect them with the Cenomanian of France are *Trigonia vicaryana*, *Pecten asper*, *P. puzosianus*, *P. subacutus*, *Lima tecta*, *Terebratula tornacensis*, *T. capillata*, *Rhynch. dimidiata*, *Cottaldia Benettii*, and *Catopygus columbarius*. The sponges *Elasmotoma* and *Trematocystia* are not uncommon.

Passing to the Midland counties, we find a continuous outcrop of Lower Chalk in the lower part of the Chalk escarpment which runs from Wiltshire to Norfolk and is broken only by the valley of the Thames. North of this valley through Berks, Bucks, Bedford, Cambridge, and Suffolk the Lower Chalk has the following composition :—

	Feet.
5. Soft grey shaly marl enclosing a band of hard white chalk, <i>Actinocamax plenus</i>	3 to 5
4. Tough blocky chalk without distinct bedding, <i>Holaster subglobosus</i> , <i>Acanth. rotomagensis</i>	60 to 80
3. Totternhoe stone, hard grey sand chalk, <i>Rhynch. Mantelliana</i> , <i>Lima echinata</i> , <i>Kingena lima</i> , <i>Pecten fissicosta</i>	2 to 20
2. Soft marls with occasional layers of hard marly rock in Oxford and Bucks, <i>Schlenb. varians</i> , <i>Rhynch. Martini</i> , <i>Inoceramus latus</i>	60 to 80
1. Marl with green grains, passing northward into the nodule bed known as Cambridge Greensand	1 to 2

The Cambridge Greensand (see Fig. 162) commences near Barton-le-Clay (north of Luton), to which locality the nodule bed in the Gault has been traced, and there can be little doubt that all the nodules and the phosphatised fossils which occur in the Cambridge Greensand have been derived from the erosion of the Upper Gault. This derived fauna comprises some 210 species of Invertebrata, and about 80 of these have not yet been recognised elsewhere in England; out of the remaining 130 no less than 114 occur in the Gault of Folkestone, nearly all the commoner fossils occurring in the Upper Gault.¹⁷ The commonest species are *Sch. rostrata*, *Hoplites auritus*, *H. raulinianus*, *Avicula gryphæoides*, *Terebratulula biplicata*, *Plicatula gurgitis*, and *Rhynchonella sulcata*, but it is noteworthy that the last is a very rare fossil in the Gault elsewhere.

The Vertebrate fauna of the Cambridge Greensand is very remarkable, the remains of many species of Ichthyosaurs, Plesiosaurs, Dinosaurs, Chelonians, and Pterodactyles having been found, together with bones belonging to a bird (*Enaliornis*). Most of these bones have doubtless been washed out of the Gault, but some may be Chalk Marl forms.

The indigenous fauna of the Cambridge Greensand is found in the marly matrix of the bed, and some of the species are *Vermicularia umbonata*, *Discoidea subucula*, *Micrabacia coronula*, *Rhynchonella lineolata*, *Kingena lima*, and *Terebratulina triangularis*, most of which occur also in the Chalk Marl above.

Another speciality of this district is the Totternhoe stone, so named from a place near Dunstable, where it is 20 feet thick, and is quarried for building purposes. It varies greatly, however, in thickness, and is sometimes represented by two beds of stone, with Chalk Marl between them. At its base there is usually a layer of green-coated phosphatic nodules, and small fragments of phosphate are common in the stone above.

In Norfolk the Lower Chalk becomes greatly reduced in thickness and at the same time harder and more purely calcareous, both these changes being evidently due to a diminution in the

quantity of intermingled argillaceous matter. Thus at Heacham and Hunstanton the stage has the following composition :—¹⁸

		Feet.
Zone of <i>Offaster</i> <i>sphaericus</i>	{ 5. Hard whitish chalk in rather thin beds	35
	{ 4. Rough dark-grey chalk with a layer of green-coated nodules at the base (Totternhoe stone)	2
Zone of <i>Schæn.</i> <i>varians</i>	{ 3. Hard creamy white chalk	13
	{ 2. Hard grey rough and shelly chalk with a layer of green-coated nodules at the base	4
	{ 1. Hard white nodular limestone	1½
		<hr/> 55½

The hard shelly chalk (No. 2) is often called the “*Inoceramus* Bed” because it is crowded with fragments of *Inoceramus* shells, probably of *Inoc. latus*. It also contains *Holaster subglobosus* and *Acanth. rotomagensis*; but the former here ranges throughout the stage, so that it is convenient to take another urchin as index for the upper zone, and for this purpose *Offaster sphaericus*, common in the upper beds of Lincolnshire and Yorkshire, seems best.

In Lincolnshire the only noticeable variations are (1) the red and pink coloration of two beds in the zone of *Offaster sphaericus* near Louth; (2) the reappearance of the Belemnite marl, which is absent near Hunstanton, but is often 2 feet thick in Lincolnshire, and is sometimes stained dark red or purple. The Totternhoe stone is a constant bed about 2 feet thick throughout the county.¹⁹

In Yorkshire the Lower Chalk maintains the Lincolnshire facies along the greater part of the escarpment, but at Speeton it shows some changes. The zone of *Sch. varians* expands to 77 feet, and the lower part consists of nodular chalk in alternating pink and white bands. The zone of *Offaster sphaericus* is 46 feet thick, and the lowest bed is in places stained pink. At the top the Belemnite marls are well marked, enclosing a medial bed of hard smooth white chalk.

Middle Chalk.—At the base of this stage there is always a certain thickness of hard nodular chalk which forms a great contrast to the soft marl on which it rests; this rocky chalk is called the Melbourn rock from a village in Cambridgeshire.

Commencing as before in Kent, we find a good section of this stage in the cliffs near Dover, which show :—

		Feet.
Zone of <i>Terebratulina</i> <i>lata</i>	{ Rather rough lumpy white chalk	20
	{ Smooth white chalk with thin layers of grey marl and several courses of flints	90
	{ White chalk with seams of marl but no flints	60
Zone of <i>Rh. Cuvieri</i>	{ Hard chalk with frequent nodular layers	38
	{ Hard and rough nodular chalk	32
		<hr/> 240

The fossils in the lower zone are *Rhynchonella Cuvieri*, *Inoceramus mytiloides*, *Cardiaster pygmaeus*, *Galerites subrotundus*, *Discoidea Dixoni*, and its variety *minima*. In the upper zone are *Terebratulina lata*, *Inoceramus Cuvieri*, and *Micraster corbovis*; here too *Spondylus spinosus* makes its first appearance, and *Holaster planus* comes in near the top.

These beds can be traced all round the Wealden area, and another fine exposure of them can be seen in the cliffs of Beachy Head, where, however, there are no flints in the zone of *Ter. lata*.

In the Isle of Wight, Culver Cliff and quarries near Yarbridge exhibit the following succession:—

		Feet.
Zone of <i>Ter. lata</i>	Rough chalk with a seam of black clay in the middle and a layer of green-coated nodules near the base	19
	Thick-bedded white chalk with seams of marl	90
Zone of <i>Rh. Cuvieri</i>	Hard chalk, becoming nodular below and containing many broken <i>Inoceramus mytiloides</i>	76
	Rough nodular chalk with marly veins	8
		<hr/> 193

Westward in Compton Bay the thickness is reduced to 150 feet. In Dorset, at Ballard Cliff, it is only 122 feet, but the same layer of green-coated nodules occurs about 20 feet from the top and has been mistaken for Chalk rock. At White Nothe Mr. A. W. Rowe estimates its thickness at 134 feet.²⁰

In Devon the Middle Chalk is well exposed near Beer, and is about 100 feet thick, the zone of *Rh. Cuvieri* here including some thickness of hard shelly chalk which is quarried for building purposes, and is known as Beer stone.

In the Midland counties this division exhibits the same lithological and palæontological characters as in the south of England. In Berkshire it is not more than 150 feet, but north of the Thames it rapidly thickens to about 220 feet, and maintains this thickness into Suffolk. The Melbourn rock at the base is from 8 to 10 feet thick, and consists of hard nodular chalk; it passes up into bedded chalk, in which *Inoceramus mytiloides* and *Rhynchonella Cuvieri* are generally abundant. The higher zone consists of soft white chalk with layers of grey shaly marl and occasional nodules of flint, which latter become more numerous towards the north, till in Cambridge and Suffolk flints are frequent in this zone and are often of elongate finger-like form. Fossils are seldom abundant, but *Galerites subrotundus* and *Terebratulina lata* occur, with *Spondylus spinosus*, *Holaster planus*, and *Micraster corbovis* in the higher part.

In the north-west of Norfolk the Middle Chalk appears to be only about 100 feet thick. The Melbourn rock continues at the base of the zone of *Rhynchonella Cuvieri*, but the beds above are less nodular than they are farther south, and the zone of *Terebratulina lata* consists of hard white chalk with many layers of flints.

In Lincolnshire there is no definite Melbourn rock, and the zone of *Rhynch. Cuvieri* is reduced to a thickness of 10 or 15 feet, consisting of yellowish-grey chalk full of fragments of *Inoceramus* shell and containing *Inoc. mytiloides*, *Rhynch. Cuvieri*, and *Terebratula semiglobosa*. At the top is a layer of grey shale, and the succeeding zone of *Ter. lata* consists of firm white chalk with frequent layers of grey flints. *Inoceramus Cuvieri* is the only common fossil, and the thickness of the zone may be 80 to 100 feet.

In South Yorkshire both zones are exposed in some large quarries near Hessle Station and have yielded a larger number of fossils, but little is known of the Middle Chalk in its course through Yorkshire except that the whole of it becomes very hard. Near Speeton, on the coast, the Middle Chalk is exposed in a fine range of cliffs and has been described by Mr. A. W. Rowe.²¹ The zone of *Rh. Cuvieri* is, as usual, in the north very thin, being less than 12 feet, but the overlying *Ter. lata* zone has expanded to a thickness of 210 feet, that fossil with small *Rhynch. Cuvieri*, *Inoceramus Brongniarti*, and *Holaster planus* being common throughout the whole of it.

Upper Chalk.—The chalk of this division has been divided into seven zones (see p. 491), but the higher zones are not everywhere present, having been removed from large areas in the south of England during the upheaval which preceded the formation of the Eocene deposits. These seven zones may be grouped into two sub-stages, the lower of which, including the zones of *Hol. planus*, *Micraster cortestudinarium*, and *M. coranguinum*, may be termed the *Micraster* chalk, while the higher zones may be called the *Belemnite* chalk until more definite names are proposed.

In Kent the Upper Chalk forms the cliffs from St. Margaret's Bay near Dover to Walmer and Deal, and again from Ramsgate round the Isle of Thanet to Margate and Reculvers, but the highest zone found in the county is that of *Marsupites*.

Mr. W. Hill finds a convenient base for the zone of *Holaster planus* in a bed which is full of scattered flints, and in which *Echinocorys vulgaris* makes its appearance.²² Measured from this the thickness of the zone is about 48 feet, and it consists of a succession of beds of rough lumpy chalk, the lumps being very hard but embedded in a softer matrix, and the top is marked by a coarse hard nodular rocky[chalk. In these beds *Micraster Leskei*, *M. præcursor*, and *Hol. planus* are common.

The complete succession of the zones exposed between Dover and Margate in descending order is as follows:—

	Feet.
Soft chalk in two sub-zones, the upper characterised by <i>Marsupites</i> and <i>Urtacrinus</i> , the lower by <i>Actinocamax granulatus</i> , and <i>A. verus</i> also occur	116
Zone of <i>Micr. coranguinum</i> . Smooth chalk with many layers of black flints; <i>Cidaris sceptrifera</i> , <i>C. perornata</i> , <i>Galerites conicus</i> , and <i>Cyphosoma Koenigi</i>	250
Zone of <i>Micr. cortestudinarium</i> . Rough nodular chalk with many flints; <i>Micraster precursor</i> and <i>Hol. placenta</i>	75
Zone of <i>Holaster planus</i> (as above described)	45
	<hr/> 486

On the coast of Sussex, however, higher zones come in. The Marsupite zone has been identified at Seaford Head, and above it is 170 feet of chalk containing *Offaster pilula*, *Actinocamax granulatus*, *Celosmilia laxa*, and other fossils of the *quadratus* zone. This chalk extends westward from Newhaven to Brighton, and thence to the valley of the Arun, where a succession of quarries between Houghton and Arundel shows parts of all the zones above mentioned (see Fig. 173). Still farther west chalk containing *Belemnitella mucronata* has been found, and this highest zone underlies the Eocene of Hampshire and is well exposed in quarries on Portsdown Hill, where an inlier of chalk is brought up within the Tertiary area by an anticlinal flexure. The total thickness of the Upper Chalk in West Sussex and Hampshire must be from 800 to 900 feet.

In the Isle of Wight the Upper Chalk forms a long and narrow outcrop across the centre of the island in consequence of the steep dip imparted to it by the flexure which carries them below the Eocene of the Hampshire basin (see Fig. 172). Its thickness is from 1200 to 1300 feet, and the thicknesses of the several zones at the western end of the outcrop, as recently determined by Mr. Rowe's measurements, are as follows:—²³

	Feet.
Zone of <i>Bel. mucronata</i> . White chalk with flints, <i>Echinocorys</i> (pyramidal form), <i>Cidaris serrata</i> , <i>Magas pumilus</i>	475
Zone of <i>Act. quadratus</i> . White chalk with some marl seams but few fossils	342
Zone of <i>Marsupites</i> . Compact white chalk with flints	80
Zone of <i>Micraster coranguinum</i> . Chalk with many layers of flint nodules and the usual fossils	310
Zone of <i>Micraster cortestudinarium</i> . Rough nodular chalk with flints	53
Zone of <i>Holaster planus</i> . Hard greyish nodular chalk	60
	<hr/> 1320

Fig. 173.—DIAGRAMMATIC SECTION ACROSS THE SOUTH DOWNS NEAR ARUNDEL by C. Reid). Distance about 7 miles.
Vertical scale about 500 feet to an inch.

7. London Clay	} Eocene.
6. Reading Beds	
5b. <i>Bel. Mucronata</i> and <i>A. quadratus</i> zones	
5a. <i>Marsupites</i> and <i>Micrasia</i> zones	
} Upper Chalk.	
4. Middle Chalk.	} Selbornian.
3. Lower Chalk.	
2. Malmstone	
1. Gault	

Fig. 174.—SECTION ACROSS THE CHILTERN HILLS FROM NEAR WALLINGFORD TO ASSENTON NEAR HENLEY. Distance about 8 miles.

5. Reading Beds (Eocene).	} Selbornian (Malmstone and Gault).
4. Upper Chalk with Chalk rock at base.	
3. Middle Chalk.	
2. Lower Chalk.	

The same zones with a total thickness of about 1000 feet are found in Dorset, where Mr. Rowe has recently identified the zone of *Marsupites* and has been able to separate the zone of *Act. quadratus* from that of *Bel. mucronata*, assigning a thickness of 354 feet to the former and not less than 250 to the latter,²⁴ the characteristic fossils of the one being *Actinocamax granulatus*, *Act. quadratus*, and *Offaster pilula*, while those of the higher zone are *Belemnitella mucronata*, *B. lanceolata*, *Cardiaster ananchytis*, *Magas pumilus*, *Crania costata*, and *Rhynchonella limbata*.

In Wiltshire and all along the inland outcrop from Salisbury Plain to Suffolk the Micraster zones are exposed in numerous chalk pits and the higher zones are all present in South Wiltshire, but north of the Vale of Pewsey the zone of *Bel. mucronata* does not occur, and that of *Act. quadratus* is gradually cut out by the pre-Tertiary planation, till the Eocene comes to lie on the *Marsupites* zone.

In all these counties the lower part of the *Hol. planus* zone consists of several beds of very hard compact chalky limestone, generally of a creamy colour, and each bed having a layer of calcareo-phosphatic nodules at the top. This limestone is known as "The Chalk Rock"; above it there is from 15 to 20 feet of greyish nodular chalk consisting of hard lumps embedded in a soft matrix. The total thickness of the zone seldom exceeds 26 feet, so that it may be regarded as a condensed equivalent of the more expanded zone to the south.

The Chalk rock frequently contains grains of glauconite and is often full of fossils, among which Gastropods are noticeable, for these are rarely found either in Middle or Upper Chalk. The most characteristic fossils are *Pachydiscus peramplus*, *Prionocyclus Neptuni*, *Scaphites Geinitzi*, *Heteroceras reussianum*, *Turbo Geinitzi*, and *Solariella gemmata*. *Holaster planus*, *Micraster præcursor*, and *M. Leskei* are also common.

The zones of *M. cortestudinarium* and *M. coranguinum* have the same characters and fossils as in the South Coast sections, as have also the higher zones as far as they can be traced, except in the case of the *Marsupites* zone which in Berkshire and the Thames Valley presents some peculiar features; for it contains two beds of brown phosphatic chalk, one at the base of the *Uintacrinus* band and one at the base of the upper division. These beds are well exposed in the large quarry at Taplow near Maidenhead, where the upper bed is 8 feet thick. The phosphatic matter is in the form of grains, some of which are casts of Foraminifera and others are phosphatised portions of *Inoceramus* shells.

In Suffolk and Norfolk the higher zones come in again from

beneath the Eocene and include the highest zone found in England, that of *Ostrea lunata*. A change also takes place in the zone of *Holaster planus*, for in Norfolk it passes into hard white chalk with dark-grey flints, without any rocky or nodular beds.

The following is a tabular view of the Upper Chalk of Norfolk, but the thicknesses of the zones are only approximate:—

	Feet.
Zone of <i>Ostrea lunata</i> . White with beds and patches of grey chalk.	
<i>Ter. gracilis</i> , <i>Thecidium vermiculare</i> , <i>Trigonosemus elegans</i> , and many Bryozoa	110
Zone of <i>Bel. mucronata</i> . Soft white chalk with many flints, some very large and cup-shaped probably	250
Zones of <i>Act. quadratus</i> and <i>Marsupites</i> . Not yet separated from the zones above and below, <i>Act. granulatus</i> common. probably	400
Zones of <i>M. coranguinum</i> and <i>M. cortestudinarium</i> . Chalk with many flints, both nodules and courses	340
Zone of <i>Hol. planus</i> (as above described)	50
	<hr/> 1150

The Upper Chalk of Yorkshire, as exhibited in the cliffs at and near Flamborough Head, has been the subject of special study first by Mr. Lamplugh and more recently by Mr. Rowe,²⁵ from whose account the following résumé is taken:—

	Feet.
Zone of <i>Act. quadratus</i> . Chalk without flints, partly seen in the cliffs near Sewerby and partly inland	330
Zone of <i>Marsupites</i> , in two bands, without flints	208
Zone of <i>M. coranguinum</i> , the upper part flintless, the lower with many flints and marl seams	260
Zone of <i>M. cortestudinarium</i> . Hard chalk with many flints	120
Zone of <i>Hol. planus</i> . Hard chalk with grey flints, both nodules and in continuous courses	125
	<hr/> 1043

With regard to its fossils the Chalk of Yorkshire differs considerably from that of Southern and Central England. Thus, *Holaster planus* being just as common in the zone of *Ter. lata* as in its own zone, one has to rely on its association with *Echinocorys vulgaris* for the recognition of the latter. The zone of *M. cortestudinarium* yields the usual assemblage, but in the overlying zone *M. coranguinum* is a rare fossil and its place is taken by *Infulaster rostratus*. Again no specimen of *Actinocamax quadratus* has been found in Yorkshire, and, *Offaster pilula* being also rare, the zone finds a local index in *Inoceramus lobatus* (= *lingua* auct., non Goldf.). It is also characterised by the abundance of fossil sponges belonging chiefly to the genera *Bolospongia*, *Scytalia*, *Seliscotho*, *Siphonia*, *Heterostinia*, *Pachastrella*, *Phymatella* and *Verruculina*, most of which do not occur in the south of England.

2. Ireland and Scotland

Ireland.—Upper Cretaceous rocks appear nearly everywhere round the edge of the great basaltic plateau of Antrim, Tyrone, and Londonderry, and we may therefore safely infer that they underlie the greater portion of it. It is also clear that they once extended much farther westward than the present edge of that plateau, as is proved by a small outlier near Draperstown. They usually rest on a planed down surface of Liassic or Triassic rocks, but sometimes overstep the limits of these, as in North-east Antrim, and rest upon the Palæozoic rocks (see Fig. 186).

These Irish Cretaceous rocks were described in 1865 by Professor Tate, and an attempt to establish a zonal classification was made by Dr. W. F. Hume in 1897, as shown in the following table :—²⁶

Tate's Divisions.	Hume's Zones.	Fect.
{ 5. White limestone	{ Zone of <i>Belemnitella mucronata</i> }	. 100
	{ „ „ <i>Actinocamax quadratus</i> }	. 3 to 5
{ 4. Chloritic Chalk	= „ „ <i>Actinocamax verus</i> .	. 3 to 4
{ 3. Chloritic sands and sandstones	{ <i>Inoceramus</i> zone (Upper Chalk)	. 6 to 16
	{ Zone of <i>Exogyra columba</i> .	. 4 to 15
{ 2. Yellow sandstones	= „ „ <i>Ostrea carinata</i> .	. 4 to 30
{ 1. Glauconitic sands	= „ „ <i>Exogyra conica</i> .	. 4 to 16

The glauconitic sands are regarded by Dr. Hume as in part equivalent to the Selbornian zone of *Sch. rostratus*, but the occurrence of *Sch. varians*, *Pecten asper*, and an *Actinocamax* like *verus* (probably *lanceolatus*, Sow.) makes it difficult to accept this view. The yellow sandstones contain layers of chert, and their fauna is a curious mixture of Selbornian and Cenomanian forms, but as the beds are shallow-water deposits it is probable that Selbornian species here survived into Cenomanian time, and the occurrence of *Acanth. rotomagensis* marks them as equivalents of Lower Chalk.

The so-called Chloritic sands appear to include two deposits of very different age, separated by a break and unconformity. The lowest beds are calcareous glauconitic sandstones with *Exogyra columba*, *Pecten asper*, and *Trigonia crenulata*, and are evidently of late Cenomanian age. The higher glauconitic sandstones, as seen north of Belfast and on the eastern coast, contain *Spondylus spinosus*, *Galerites conicus*, *Rhynchonella limbata*, *Rh. plicatilis*, and a species of *Micraster* with many broken *Inocerami*. These beds pass up into a glauconitic sandstone, often pink in colour, which yields *Echinocorys vulgaris*, var. *gibbus*, and a few other fossils.

If the fossils are correctly identified these zones of *Sp. spinosus* and *Ech. gibbus* must be regarded as a condensed representative of

the *Micraster* zones of the English Chalk; the whole of the Middle Chalk and perhaps that of *Hol. planus* also being absent.

Above the "Chloritic chalk" is the "White Limestone," which has a bed of nodular chalk at its base containing *Act. verus* and many sponges, and in the north of Antrim a similar nodular bed is succeeded by 5 feet of flintless chalk containing plates of *Marsupites*. Finally in conformable succession is white chalk with many flints, about 100 feet thick, having *Act. quadratus* near the base and *Bel. mucronata* in the higher part.

Scotland.—Cretaceous rocks are found again especially on the west coast of Scotland, in the island of Mull and in the district of Morvern on the adjacent mainland; as in Ireland, they belong exclusively to the upper division of the system, and though they can be correlated generally with the Irish Series, they exhibit a still more abnormal facies and a more decided approach to littoral conditions. They are best exposed in Morvern, along the shores of Loch Aline, and beneath the singular outlying masses of Beinn-y-Hun and Beinn-y-Hattan.²⁷ The general succession here is:—

	Feet.
4. Sandstones and white marls with plant remains (high Cretaceous or early Eocene)	20
3. White indurated chalk with bands of flints, <i>Belemnites</i> <i>mucronata</i> , and fragments of <i>Inoceramus</i> ; some beds of glauconitic chalk at the base	10
2. White sandstones without fossils, but containing a thin seam of coal	30 to 100
1. Glauconite sands, passing sometimes into dark-green argillaceous sand, sometimes into calcareous sandstone; <i>Pecten asper</i> , <i>P. orbicularis</i> , <i>Exogyra conica</i> , but no <i>Ammonites</i>	20 to 60

On comparing these beds with those of Antrim we may safely regard No. 1 as equivalent to Nos. 1 and 2 of the Irish sequence.

The overlying white sandstones (No. 2) would appear to be homotaxial with the zone of *Ostrea columba* in Ireland, whatever the precise age of that may be. Above it there is a palæontological break, though apparently no unconformity, and the hard white chalk corresponds closely to that of Ireland, except that there is no sign of the *Micraster* zone at its base.

D. CONTINENTAL REPRESENTATIVES

1. Northern France

In France the Cretaceous exhibits two very different facies, that of the southern provinces being very different from that of the northern region, which is often called the Paris basin. The deposits found in the latter closely resemble those of England, and

were evidently formed in the same sea, while those of Southern France belonged to a different marine province. Those of the Paris basin may first claim attention, and the following is a brief notice of them (see table on p. 491).

Albian.—The name of this stage is taken from the river Aube (or Alba), and in the department of that name it consists of the following members:—

	Feet.
Marls with <i>Schlenbachia rostrata</i> and <i>Ostrea vesiculosa</i>	up to 200
Clays with <i>Hoplites splendens</i> and <i>H. auritus</i>	„ 30
Clays with <i>Hoplites interruptus</i> and <i>Douvillerias mamillatum</i> „	60
Green sands without fossils	„ 30

Traced northward into the Departments of the Meuse and Ardenne the basal sands contain *D. mamillatum*, and pass into a siliceous rock (the “gaize de Draize”). The marls also pass into similar rock (the “gaize de l’Argonne”), which closely resembles our malmstone, and is undoubtedly of the same age. Still farther north, near Mons, the zone of *Sch. rostrata* overlaps the lower beds, and is represented by sands with layers and nodules of chert, the fauna resembling that of the Blackdown sands in Devon.

These Albian deposits pass completely under the Paris basin. They have been reached by deep borings at Paris and Dieppe. They appear again in the anticlinal uplift of the Pays de Bray, and in diminished thickness they are found in the cliffs of Normandy. Near Cap la Hève the clays are about 10 feet, and the gaize with *Schlenbachia rostrata* is about 26 feet thick.

Cenomanian.—The district where this stage was first established, that of Le Mans in the Sarthe, is unfortunately one where the beds have a sandy and shallow-water facies, and are difficult to compare with the chalky facies which prevails in the eastern part of the Paris basin as it does in England. In Normandy, however, there is an intermediate type which affords valuable assistance in the correlation, and a fine section of it is visible in the cliffs near Cap la Hève:—²⁸

	Feet.
4. Greyish-white chalk with grey flints	about 30
3. Grey chalk with cherts and phosphatic nodules	„ 10
2. Yellowish-grey silty and glauconitic chalk with many layers of grey and black cherts, and some beds of bluish marly chalk near the bottom	„ 84
1. Bluish-grey sandy glauconitic marl with black phosphatic nodules and many fossils	„ 6

The basement bed contains *Stauronema Carteri* and *Schlenbachia varians*, and is the equivalent of our Chloritic marl. The beds above contain *Schlenbachia varians*, *Acanthoceras Mantelli*,

Turritiles costatus, *Pecten asper*, *P. Galliennei*, and *Holaster subglobosus*. Most of these also range into No. 3, but the whitish chalk above has few fossils.

Turonian.—The name of this stage is taken from Touraine, where it is divisible into two sub-stages called (1) the Ligerian and (2) the Angoumian.

Angoumian	{	Calcareous sands and sandy limestones with <i>Callianassa</i> , <i>Ostrca columba</i> , and <i>Acanthoceras Deverie</i> , 30 feet.
		Yellow sandy chalk with <i>Acanthoceras deverioides</i> .
Ligerian	{	Micaceous chalk with <i>Prionotropis Woolgari</i> , <i>Pachydiscus peramplus</i> , and <i>Mammites Revellieri</i> (= <i>Rochbrunei</i>), 60 to 100 feet.
		Marly chalk with <i>Rhynch. Cuvieri</i> , <i>Inoceramus labiatus</i> , and <i>Galerites subrotundus</i> , 30 feet.

Traced northward into Normandy these beds pass into pure chalk, and near Rouen the facies is the same as in England with a thickness of about 280 feet. At the base is hard nodular chalk like our Melbourn rock, succeeded by chalk with *Mammites nodosoides*, *Prionotropis Woolgari*, and *Galerites subrotundus*, and this by soft chalk with *Terebratulina lata*, the higher parts of which contain *Holaster planus* and *Micraster Leskei*.

Senonian.—For this stage I retain d'Orbigny's original name instead of the awkward one of *Emscherian* which has been adopted by de Lapparent or the *Corbiérian* of de Grossouvre. The original name should not be dropped, and should be specially applied to that portion of the Chalk which is typically developed round the town of Sens and in the country of the ancient Senones. This comprises the *Micraster* zones, i.e. those of *M. decipiens* (or *M. cortestudinarium*), *M. coranguinum*, and of *Marsupites* (or *Micraster turonensis*).

In the Departments of the Yonne, Aube, and Marne, this stage consists entirely of white chalk, in which flints are often but not universally numerous, and it has a thickness of from 400 to 500 feet. Northward in the Aisne and in Picardie it passes into grey and dolomitic chalks with a less thickness, and on the western side of the Paris basin it is represented by sandy marls, hard limestones, and fine siliceous deposits ("tuffeaux"), the full thickness of which at Villedieu and Saumur is little more than 100 feet. According to M. de Grossouvre the "craie de Villedieu," containing *Spondylus truncatus*, *Micraster turonensis*, with species of *Mortonicer* and *Peronicer*, is the equivalent of the *Marsupites* zone.

Campanian.—This stage is typically developed in the district of Champagne, whence it takes its name, and where it has been divided into four local zones. It comprises the broader zones of *Actinocamax quadratus* and *Belemnitella mucronata*, which have a

total thickness of about 250 feet, and its highest portion is found in the chalk of Mendon near Paris.

In the Campanian should be included a still higher zone, sometimes called *Maestrichtian*, which is found in Belgium near Ciply and Maestricht and in a small isolated patch in the Cotentin (Normandy). At Ciply there is a continuous series of chalks up to the top of a phosphatic and glauconitic chalk in which the little Brachiopod *Thecidea papillata* is abundant. Resting unconformably on this is a conglomerate of rolled phosphate nodules and fossils which forms the base of the "Tuffeau de St. Symphorien," a soft yellowish rock composed largely of Bryozoa and containing occasional grey flints. Its fossils include *Belemnitella mucronata*, *Baculites Faujasi*, *Ostrea larva* (= *lunata*), *Thecidea papillatum*, and *Terebratula carnea*. At Maestricht in Limbourg the series is carried a step higher, the tuffeau with flints being overlain by another set of limestones (120 feet thick), consisting of alternating soft and hard beds. These also yield *Bel. mucronata* and *Ostrea larva*, with *Hemipneustes striatoradiatus*, some Gastropoda, and remains of the marine reptile *Mosasaurus Camperi*.

Some writers include the *Maestrichtian* in the *Danian*, but it is better to restrict the latter to deposits which are destitute of *Ammonites* and *Belemnites*. Thus restricted there is no *Danian* in the north of France or Belgium.

2. Denmark and Sweden

The Upper Cretaceous deposits of these two countries are of special interest, because they carry the series continuously up to a higher horizon than is found in England or France, and include beds which seem to bridge the interval between Cretaceous and Eocene. Those of Scania also are transgressive and indicate the gradual northward extension of the Cretaceous Sea, which did not begin to encroach on Scandinavian land till the close of the *M. coranguinum* zone. In fact, nothing older than this zone is exposed in either country. The Danish Beds are seen at Faxe and Saltholm, where the succession is :—

5. Chalky limestone with flints, *Nautilus danicus*, *Holaster faxensis*, *Ananchytes sulcatus*, *Terebratula carnea*.
4. Limestone with *Cerithium faxense* and *Baculites vertebralis*.
3. Clay with fish remains and *Ostrea lateralis*.
2. White chalk with *Belemnitella mucronata*.
1. Chalky limestone with *Actinocamax granulatus*.

No. 2 is regarded as the top of the Campanian, and the higher beds as a separate stage under the name of *Danian*.

In Sweden the most complete succession is found near Malmo and in the basin of Ystad, the highest beds being found at the former and the lower at the latter locality. The total thickness appears to be more than 1500 feet, and the combined succession is as follows :—

Danian.	{	Grey and white chalks without Belemnites or Ammonites, but containing <i>Nautilus danicus</i> , <i>Ananchites sulcatus</i> , two species of <i>Cypræa</i> and one of <i>Pleurotomá</i> .
Campanian.	{	White chalk with flints of Malmo, and sandy glauconitic marls of Kopinge with <i>Belemnitella mucronata</i> and <i>Magas pumilus</i> .
Granular limestone with <i>Actinocamax mammillatus</i> .
Marl with <i>Act. quadratus</i> , passing into a conglomerate at Tosterup with <i>Ostrea vesicularis</i> , <i>O. semiplana</i> , and <i>Inoc. latus</i> .
Senonian.	{	Marly limestones with <i>Actinocamax granulatus</i> and <i>A. verus</i> with <i>Inoceramus lingua</i> and <i>Scaphites binodosus</i> .
Marls with <i>Actinocamax westphalicus</i> .

To the northward near Christianstad the Senonian is absent, and the *quadratus* beds rest directly on the Archæan platform with a basal conglomerate. By some authors the Danian is regarded as equivalent to the *Montian* of Belgium (see Chap. xv.), but its fauna is different and more closely allied to the Cretaceous.

3. The Mediterranean Region

A different facies is found in Southern France, Spain, and through the whole of Southern Europe from the Alps and Italy to the shores of the Black Sea. The *Albian* of this region consists mainly of sands and sandstones, the *Cenomanian* of sandy limestones containing *Orbitolina* (*Patellina*) *concava* and many species of *Caprina*, *Caprotina* and *Caprinula*. The *Turonian* and *Senonian* are also represented by sandstones, sandy limestones, and marls abounding with other genera of irregular Lamellibranchs, such as *Hippurites*, *Radiolites*, and *Sphærolites*, some of the beds being known as Hippurite limestones. These two divisions reach a thickness of 1500 feet in some places. The higher stages are more local, but often comprise a great thickness of strata; thus in Provence they include some marly limestones of *Campanian* age, succeeded by a vast group of freshwater deposits (the *Garumnian*), having a thickness of 2500 feet and yielding a large number of freshwater and terrestrial shells. In character and thickness this group is analogous to the English Wealden.

The most complete succession of marine deposits in the south of

France is that of Aquitaine, and may be given as an illustration of the lithological development of the Mediterranean facies. According to M. Coquand and M. de Grossouvre it is as follows :—²⁹

Danian.	{	Limestones of Tercis, with <i>Micraster terciensis</i> , in two zones, separated by <i>Miliolina</i> limestones and lacustrine deposits, the whole about 600 feet thick.
Campanian.	{	Reddish-yellow limestone with <i>Baculites anceps</i> , <i>Pachydiscus colligatus</i> , <i>Turritiles polylocus</i> , and <i>Thecidea papillata</i> .
	{	White limestone with Bryozoa and <i>Belemnitella mucronata</i> .
	{	White marly limestones with <i>Actinocamax quadratus</i> , <i>Scaphites binodosus</i> , <i>Inoceramus latus</i> , and <i>Exogyra</i> .
Senonian.	{	Sandy limestone with <i>Spondylus truncatus</i> , <i>Hippurites</i> , and <i>Radiolites</i> .
	{	White and grey limestones with <i>Mortonicerias texanum</i> .
	{	Hard nodular limestones with <i>Scaphites Meslei</i> , <i>S. Lamberti</i> , and <i>Micraster turonensis</i> .
Turonian.	{	Soft limestones and marls with <i>Sphærulites</i> .
	{	Soft beds with <i>Radiolites</i> , <i>Hippurites</i> , <i>Sphærulites</i> , and <i>Acanthoceras Deveria</i> .
	{	Nodular limestone with <i>Prionotropis Woolgari</i> .
	{	Marls with <i>Ostrea columba</i> .
Cenom.	{	Sands, clays, and limestones with <i>Ostrea</i> , <i>Caprina</i> , <i>Schlœnbachia varians</i> , and <i>Turritiles costatus</i> .
Albian.	{	Only found on the Pyrenean side of the basin, where it is represented by black marls and limestones.

4. Germany, Bohemia, and Silesia

In Westphalia and Northern Germany there is an Upper Cretaceous Series comparable to that of England and the north of France, having Gault Clays and marls at the base, succeeded by Cenomanian marls and a thick mass of chalk which includes representatives of the Turonian, Senonian, and Campanian stages.

Farther east, however, in Saxony, Bohemia, and Silesia, a different facies is found, where terrigenous sandy material prevails over that of organic origin, the chalky limestones of Western Europe being largely replaced by sandstones which the Germans call "Quaderstein," because they are much jointed, and split into square blocks. The following is the general succession in this area according to Schlönbach and Fritsch :—

Senonian.	{	Chlomek	{	Sandstones with <i>Placenticeras Orbigny</i> , <i>Peroniceras</i>
		Beds	{	<i>subtricarinatum</i> , and <i>P. westphalicum</i> .
	{	Priesen	{	Clays with ironstone nodules, <i>Placenticeras Orbigny</i>
		Beds	{	and <i>Scaphites Lamberti</i> .
			{	Marls with <i>Pachydiscus peramplus</i> , <i>Prionotropis Neptuni</i> , and <i>Baculites bohemicus</i> .

Turonian.	Teplitz Beds	{ Marls and limestones with <i>Micrasters</i> , <i>Scaphites Geinitzi</i> , and <i>Pachydiscus peramplus</i> .
	Malnütz Beds	{ Sandstones with <i>Inoceramus Brongniarti</i> . Glauconitic sandstones with <i>Mammiles nodosoides</i> and <i>Rhynchonella bohémica</i> .
	Weisemberg Beds	{ Sandy limestones and marls with <i>Spondylus spinosus</i> . Sandstones with <i>Inoceramus labialus</i> , passing north-west into marly limestones.
Cenom.	Korycan Beds	{ Sandstones and sandy limestones with <i>Acanthoceras rotomagensis</i> , <i>Scaphites aequalis</i> , and <i>Baculites baculoides</i> .
	Perutz Beds	{ Sandstones and shales with plant remains resting on pre-Cretaceous rocks.

The highest beds of this series represent the zone of *Micraster coranguinum*, nothing higher having been found in any part of the area.

5. Russia

Strata of Upper Cretaceous age occupy large areas in Southern and Central Russia, though the exposed portions are not of great extent, because so much is concealed beneath a covering of Tertiary Beds. The deposits are of great thickness, and must include representatives of the Cenomanian, Turonian, and Senonian stages, but though Greensands with Cenomanian fossils occur at the base, fossils are scarce in the overlying chalks and marls, so that no zones have been established; moreover no definite Turonian division has been recognised, for there seems to be an intermingling of species which in Western Europe would be regarded as Turonian and Senonian.

Useful information concerning the Russian Chalk was collected in 1892 by Dr. W. F. Hume,⁸⁰ who describes the mass of the formation as consisting of grey and white chalks with a band of marly chalk or "Chalk Marl" between them. A boring at Kharkov has proved the great thickness of these beds, and the details given by Dr. Hume may be thus summarised:—

	Feet.
Tertiary deposits	133
Soft white chalk without flints	967
Bluish and grey marly chalk	391
Grey chalk	312
White chalk with flints	161
Grey and green sands and sandy clay	93

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The higher white chalks contain *Bel. mucronata* in abundance, and this species is said also to occur in the marly chalks. These deposits extend all across Southern Russia from Podolia and Volhynia on the west to Voronetz, Saratov, and Simbirsk on the

east. From Poland and Silesia another band of chalk is believed to extend across the Moscow basin, but no deposits of Upper Cretaceous age have been found in Northern Russia, though it seems likely that they originally spread over those of the Lower Series.

E. THE HISTORY OF THE PERIOD

The history of Cretaceous time in Europe is the history of the gradual submergence of the large tracts of land which existed in the region at the beginning of the period. These tracts included (1) a large area in the north which may be called the Fenno-Scandian region; (2) a western land including the British area, the whole of Western France, and the greater part of Spain; this may be called the Atlantic region; (3) a long tract extending from the north-east of France through Central Europe, Bohemia, and the southern part of Russia, which for want of a better name may be called the Hercynio-Sarmatian land. The Atlantic and Hercynian regions were connected by a broad isthmus across Belgium and the North Sea, and it is also possible that there was a land-connection between the Fenno-Scandian and the Sarmatian regions.

There is fairly good evidence that some of this land rose to a considerable elevation above the sea-level of early Cretaceous time, because some parts of it were never entirely submerged even after the deposition of several thousand feet of strata and the formation of chalk below water which must have been over 3000 feet deep. We know also that there were both large rivers and large lakes on this continent, and we know the actual position of two of these lakes. The one, known as the Wealden lake, occupied a large part of Southern England with the adjacent parts of what is now the English Channel. The other occupied a large area in the north-west of Germany, and appears to have been connected with the estuary of a river which opened into a gulf of the Northern Sea.

With regard to the Wealden lake, I think there is no doubt about its having been an enclosed inland lake with an excurrent river emerging from its southern side and running south-eastward through France. In spite of the views held by certain French geologists, there is no good reason for believing that the Southern Sea invaded the Pays de Bray or the Boulonnais before Aptian time. The few species of Lamellibranchs on which they rely for the presence of the Hauterivian Sea in the Pays de Bray are all found in the Vectian of the Isle of Wight. The northern termination of this sea appears to have been in the Haute Maine, where its characteristic fauna occurs in a limestone overlying a set of freshwater beds, some 60 feet thick. Such a conjunction seems

to indicate the estuary of a river, which was probably that flowing out of the Wealden lake.

It is generally admitted that during the earlier part of this epoch, *i.e.* during Wealden and Neocomian times, land existed in the north-east of France and over Belgium and that it was connected with land over the east of England. It is my own opinion that this was a fairly broad tract of land enclosing the Wealden lake and connecting the western land with that of Central Europe. Further, I hold that this isthmus was never broken through till the Aptian epoch, when the Northern and Southern Seas met in a strait which passed obliquely across England from Wiltshire to Cambridge and Norfolk.

We may now turn our attention to the general position and extensions of these Southern and Northern Seas. The former appears to have covered most of Eastern France (south of the Ardennes), and to have stretched eastward through Switzerland and Italy across the southern part of Austria and the Danubian provinces to the Black Sea and the Crimea. The Northern Sea occupied a large part of what is now the Arctic Ocean and extended southward in two great gulfs, one on each side of the Fenno-Scandian land.

The western gulf touched the north of Scotland (Caithness and Aberdeen), and seems to have passed southward through the North Sea area into Yorkshire and Lincolnshire on the one hand and into Germany on the other. The eastern gulf occupied a large part of Northern Russia, extending southward to the Moscow basin and south-east to the province of Simbirsk; but near Moscow the sea was shallow, as the zone of *Bel. Jasekowi* is there represented by sands with plant remains but no marine fossils, so that they seem to be of brackish or freshwater origin.

The question remains whether there was any water-connection between the extremities of the eastern and western gulf, or whether Fenno-Scandia was united to the Sarmatian land. So far as the similarity of the English and Russian faunas is concerned, that both were derived from the Northern Ocean is sufficient explanation. The only evidence for the theory that the gulfs were otherwise connected is the existence of some deposits of Lower Cretaceous age at Brzezine on the borders of Posen and Poland, where freshwater beds with *Cyrena* and *Cypris* are succeeded by sands and conglomerates which are overlain by clays with *Astarte* and *Exogyra Couloni*; but these bivalves may be of any zonal age, and only indicate the line along which the sea eventually made its way across the space between Hanover and Moscow.

Having regard to the presence of freshwater deposits of early

Cretaceous age in Hanover, Posen, and the Moscow area, it seems probable that Prussia and Poland were land surfaces at this time (see Fig. 175) and were not submerged till Aptian or Albian times. We know that it was in Aptian time that the subsidence carried the sea across the English isthmus, and it may well have been at the same epoch that a strait was formed across Prussia and that Fenno-Scandia was reduced to the condition of a large island.

In Albian and Cenomanian times there was a more rapid subsidence, and the continental land was broken up into a number of islands. The Southern and Northern oceans were united across France and England, much of the Sarmatian land was submerged, and the central area was reduced to an island which, at any rate in Cenomanian time, extended only from the Ardennes to Bohemia.

Minor changes subsequently took place, with a temporary elevation of the Franco-British area, during the time of the *Holaster planus* chalk, but the renewed subsidence of Senonian time must have still farther reduced the land-areas till the only remaining large tract of land in the European region was that of Fenno-Scandia, for of this only a small portion was ever submerged.

This subsidence appears to have reached its maximum during the Campanian epoch, for the zones of *Actinocamax quadratus* and *Belemnitella mucronata* seem to have had the widest extension both over Limbourg and over Scania. At this time it is probable that the British area was reduced to an archipelago of islands (see *Building of the British Isles*, 1911), and it is doubtful whether any part of England remained above water; even of Wales only those parts continued as islands which are now more than 2000 feet above the sea.

French geologists seem to have taken it for granted that Brittany and the Central Plateau of France still formed islands in the Senonian and Campanian Seas; apparently because no trace of Cretaceous strata has been found upon them. But the existence of land cannot be postulated on negative evidence; the question to be considered is how far the chalk of neighbouring areas is likely to have been prolonged over them. In the case of Brittany we have every reason to suppose that Turonian, Senonian, and higher chalks followed the Cenomanian over the Cotentin and down the Channel area; and as no part of Brittany rises to more than 1400 feet above sea-level, while Dartmoor rises to 2000, it seems probable that if the latter was entirely submerged, the former was also.

With respect to the Central Plateau there is more to be said. Since the central and southern portions of it are over 5000 feet above existing sea-level, it might be thought that these must have remained above that of the Cretaceous Sea; but we must remember

that these parts were the scene of prolonged volcanic activity in Tertiary time, and that they were doubtless then raised to a higher relative level than they had previously occupied, for the north-west part of the plateau does not rise to more than 3000 feet.

The facts which have chiefly to be considered are the characters of the Upper Cretaceous deposits which surround the Central Plateau. Those on the north and north-east sides are chalks which have the character of deep-sea deposits, being fine foraminiferal oozes in which *Textularia* and *Globigerina* are the prevalent forms. On the north-west the Senonian is largely a Bryozoan deposit formed in no great depth of water, and the Campanian is a siliceous rock analogous to "gaize," and mainly composed of sponge spicules; this may have been accumulated in water of 200 to 300 fathoms (about 1500 feet). On the south-east side in Aquitaine we find the Senonian composed of marly limestones, which are often sandy and include banks of Hippurite and Radiolite limestone, deposits which are not of deep-water origin. The Campanian of the same area, however, consists for the most part of fine white chalky limestones in alternating solid and crumbly beds with layers of black flints. M. de Grossouvre describes this material as similar to chalk, and as "denoting a deposit formed at a much greater distance from shores, and in much deeper water than the sediments" of the Senonian.³¹

The successive stages of the series probably passed progressively one beyond the other on to the flanks of the Central Plateau, and if the average depth of water under which the Campanian sediments was deposited was only 400 fathoms (*i.e.* 2400 feet), it is clear that large parts of the plateau must have been submerged; how much would require a special study to determine.

From the Campanian subsidence there was a gradual recovery, accompanied by a certain amount of lateral pressure which produced a warping or upward flexure of parts of the mass of deposit, so that a series of broad anticlines and synclines were formed, and the summits of the anticlines were planed off by the currents and waves of the shallowing seas. Hence, as we shall see, even the earliest Eocene deposits are more or less unconformable to the underlying Cretaceous strata.

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CHAPTER XV

TERTIARY OR CÆNOZOIC TIME

PALÆOGENE SYSTEM

As explained on p. 11, the Tertiary deposits are usually divided into five or six groups with a nomenclature based on the proportional number of species of Mollusca found in each group that have survived to exist at the present day. But these groups cannot be regarded as systems of the same palæontological value as those into which the Mesozoic and Palæozoic rocks have been divided. Only two such systems can be recognised in Cænozoic time, the *Eocene* and *Oligocene* divisions forming one system, the *Miocene*, *Pliocene*, and *Pleistocene* divisions forming a second. For these two systems the German geologist Hoernes proposed the names *Palæogene* and *Neogene*, signifying the older and the newer kind of Tertiary life, and though not altogether satisfactory names, they have been widely adopted on the European continent.

The older Tertiaries of North-western Europe occur in several basins or broad trough-shaped areas, separated by parallel anticlines or axes of elevation. The most northern of these is known as the London basin, which, however, is only the western part of a large geo-syncline extending from Belgium across the North Sea and terminating in Wiltshire. A second but much smaller basin is known as the Hampshire basin, extending through Sussex, Hampshire, and Dorset, but bounded on the south by the sharp anticline which runs through the Isle of Wight and the Isle of Purbeck. A third is the Paris basin, occupying a broad depression in the Chalk area of Northern France. South of this, again, are the two separate basins of Aquitaine and Provence.

Some account of the Palæogene deposits in all these areas will be given in the following pages, taking first the Eocene and afterwards the Oligocene Series.

I. THE EOCENE SERIES

This series has been divided into a number of stages for which different names are at present used in England, France, and Belgium, as shown in the following table:—

England.	Belgium.	France.
Barton Beds.	Wenmelian.	Bartonian.
Bracklesham Beds.	Laekinian and	Lutetian.
Bagshot Beds.	Brussellian Beds. }	
London Clay.	Sables de Mons. }	Ypresian.
Woolwich and	Argile de Flandres. }	
Reading Beds. }	Upper } Landenian.	Sparnacian.
Thanet-Beds.	Lower }	Thanetian.
	Montian.	Montian.

A. LIFE OF THE PERIOD

Eocene Life.—The difference between the fauna of the Chalk and that of the Eocene is very great indeed, for only one species, and that is a Brachiopod (*Terebratulina striata*), seems to have survived the change of conditions in Britain, and not only so, but the general aspect of the Eocene fauna is quite different from that of the Cretaceous. The great reptiles of the Secondary rocks have disappeared, and with them the numerous Cephalopods which are so characteristic of the Cretaceous System—the Ammonites, Turritiles, Baculites, Scaphites, Hamites, Belemnites, and many other genera; vanished also are the Hippurites, Radiolites, and Inocerami of the Chalk, most of the Cretaceous Echinoderms, and all the deep-sea siliceous sponges (*Ventriculites*, *Cephalites*, *Plocospongia*, etc.).

In England the most abundant fossils are Gastropods and Lamellibranchs, many of them belonging to genera which now characterise much warmer seas than those around our islands. Brachiopods, Echinoderms, Corals, and Sponges are rare compared with their numbers in Mesozoic deposits.

The Eocene flora is marked by the abundance of Dicotyledons, especially of genera which now occur in tropical and sub-tropical regions. It should be mentioned, however, that many of the genera which now make their appearance in Britain occur in the higher Cretaceous deposits of the continent. The flora of the Woolwich and Reading Beds has a temperate aspect; it includes leaves like those of the poplar, plane, and hazel (*Populus*, *Platanus*, and *Corylus*). The plants of the London Clay and Bagshot sand, on the other hand, are those of a much warmer climate; they include leaves and fruits of the conifers *Pinus* and *Sequoia*, with

the palms *Nipa*, *Sabal*, and *Areca*; the Dicotyledons *Ficus*, *Aralia*, *Dryandra*, *Cassia*, *Eucalyptus*, *Magnolia*, *Cactus*, and many kinds of *Leguminosæ*. In the Bournemouth Beds a still larger number occur, and form a different assemblage, but still one of sub-tropical aspect; this includes ferns of the genera *Osmunda*, *Chrysodium*, *Pteris*, and *Gleichenia*, the palms *Sabal*, *Iriarteia*, *Flabellaria*, *Phœnicites*, and a large number of Dicotyledonous leaf impressions which have not yet been properly determined.

Of invertebrate animals the following are the principal genera which now make their appearance in Britain, though some of them (particularly the Gastropods) really date from the Upper Cretaceous Beds of Europe :—

<i>Protozoa.</i>	Alveolina, Nummulites.
<i>Actinozoa.</i>	Balanophyllia, Dendrophyllia, Goniopora (= Litharea), Madrepora, Oculina, Paracyathus, Solenastrea, Turbinolia.
<i>Echinoderma.</i>	Schizaster, Spatangus.
<i>Crustacea.</i>	Dromia, Mithracia, Portunites, Xanthopsis.
<i>Lamellibranchia.</i>	Corbicula, Diplodonta, Potamomya, Sanguinolaria, Verticordia.
<i>Gastropoda.</i>	Ancilla, Cassis, Conus, Conorbis, Cypræa, Fasciolaria, Marginella, Oliva, Pyruia, Rostellaria, Rimella, Sycum (= Leiotoma), Tritonium, Trophon, Typhis, Voluta, Xenophora.
<i>Cephalopoda.</i>	Aturia, Beloptera, Belosepia.

Vertebrate animals are now abundant, the four great classes of fish, birds, reptiles, and mammals being all represented, though remains of birds are rare. The following are some of the genera found in the Eocene Series of England and France :—

<i>Pisces.</i>	Myliobatis, Ætobatis, Pristis; Lepidosteus, Phyllodus; Cœlopoma, Goniognathus, Splyrænodus (= Dictyodus); Percostoma, Scienurus, and others.
<i>Reptilia.</i>	Gavialis (a crocodile); Lacerta (a lizard); Palæophis (a sea-snake); Trionyx, Lytoloma, Argillochelys (tortoises).
<i>Aves.</i>	Argillornis, Dasornis, Gastornis, Halcyornis, Eupterornis, Lithornis, Odontopteryx, all large birds. Odontopteryx had a large beak furnished with tooth-like processes.

Mammalia.—These deserve more special description. Marsupials of the genus *Didelphys* were common, and with these are carnivores (*Arctocyon* and *Palæonictis*) with strong marsupial affinities, but believed to be really placentals; a little later appear other carnivora, *Pterodon*, and *Proviverra*. The earliest known ungulate is *Coryphodon*, a primitive tapir from the Woolwich Beds and London Clay. Still later other genera appeared, *Lophiodon*,

Pachynolophus, *Paloplotherium*, all related to tapirs and rhinoceroses, with *Hyracotherium*, which combined characters now found in the coney (*Hyrax*) and in the pigs. Other hog-like animals (*Hyopotamus*) appear in the Upper Eocene and become common in Oligocene time. There were also primitive hornless forms of deer or antelope named *Dichodon* and *Amphitragalus*. Early forms of the Proboscidea have been found in the Upper Eocene of Egypt. Sirenia are represented by *Eotherium*, etc. The rodents were represented by

Fig. 176.—FOSSILS OF THE THANET BEDS.

a. <i>Cucullæa decussata</i> .	d. <i>Cyprina planata</i> .
b. <i>Pectunculus terebratularis</i> .	e. <i>Pholadomya cuneata</i> .
c. <i>Protocardium Laytoni</i> .	f. <i>Corbula regulbiensis</i> .
g. <i>Aporrhais Sowerbyi</i> .	

Theridomys and *Sciuroides*, and the primates by the Lemuroid *Microchærus*.

Characteristic Fossils.—The following are some of the commoner and most characteristic species of invertebrates found in the marine and estuarine deposits of the Eocene Series :—

Fossils of the Thanet Beds

- Lamellibranchia*. *Protocardia Laytoni*, *Corbula regulbiensis*, *Cucullæa decussata* (= *crassatina*), *Pectunculus terebratularis*, *Cyprina scutellaria* (= *planata*), *C. Morrisi*, *Astarte tenera*, *Pholadomya cuneata*.
- Gastropoda*. *Aporrhais Sowerbyi*, *Trophon subnodosum*, *Scala Bowerbanki*.

Fossils of the Woolwich and Reading Beds

Lamellibranchia. Corbicula cuneiformis, C. tellinella, Cyprina Morrissi, Ostrea bellovacina, O. tenera, Unio subparallela.

Gastropoda. Potamides funatus, Calyptra aperta (= trochiformis), Melanopsis buccinoidea, Melanatria inquinata, Neritina globulus, Pitharella Rickmani.

Fig. 177.—FOSSILS OF THE WOOLWICH BEDS.

- a. Melanina inquinata.
b. Potamides funatus.
c. Pitharella Rickmani.
d. Ostrea bellovacina.

- e. Unio subparallela.
f. Ostrea tenera.
g. Corbicula cordata.
h. Corbicula tellinella.

Fossils of the London Clay

Annelida.
Crustacea.
Brachiopoda.

Ditrupa plana, Vermicularia bognoriensis.
Hoploparia Belli, Xanthopsis Leachi.
Lingula tenuis, Terebratulina striatula.

Lamellibranchia. *Cardita Brongniarti*, *Axinus angulatus*, *Dosiniopsis orbicularis*, *Pholadomya margaritacea*, *Pinna affinis*, *Modiola elegans*, *M. depressa*, *Panopæa intermedia*, *Pectunculus decussatus*, *P. brevirostris*.

Fig. 178.—FOSSILS OF THE LONDON CLAY.

a. <i>Cardita Brongniarti</i> .	d. <i>Cassidaria ambigua</i>	g. <i>Pleurotoma teretrium</i> .
b. <i>Panopæa intermedia</i> .	e. <i>Nipa elliptica</i> (fruit).	h. <i>Voluta Wetherelli</i> .
c. <i>Hoploparia Belli</i> .	f. <i>Terebratulina striatula</i> .	i. <i>Nautilus imperialis</i> .

Gastropoda.

Aporrhais Sowerbyi, *Cassidaria ambigua*, *Xenophora extensa*, *Pisania* (*Tritonidea*) *Morrisi*, *Natica hantoniensis*, *Sycum* (*Leiostoma*) *globatum*, *Pleurotoma* (*Surcula*) *teretrium*, *Pyrula Smithi*, *Voluta Wetherelli*, *Volutospina elevata*.

Cephalopoda.

Nautilus imperialis, *N. regalis*, *Aturia ziczac*.

*Fossils of the Bracklesham Beds**Protozoa.*

Nummulites lævigatus, N. variolarius.

Actinozoa.

Goniopora (= Litharæa) Websteri.

Lamellibranchia.

Arca biangula, Pecten corneus, Cardita (Venericardia), planicosta, Solen obliquus, Sanguinolaria Holloyi, Pectunculus pulvinatus.

Fig. 179.—FOSSILS FROM THE BRACKLESHAM AND BARTON BEDS.

a. Litharæa Websteri.

d. Chama squamosa.

g. Conorbis dormitor.

b. Nummulites lævigatus.

e. Corbula pisum.

h. Clavella longæva.

c. Ostrea flabellula.

f. Crassatellites sulcatus.

i. Murex asper.

Gastropoda.

Clavella longæva, Sycum (Leiostoma) pyrus (range into Barton Beds), Cassidaria coronata, Cypræa tuberculosa (var. Coombii), Cerithium (Campanile) giganteum, Turritella imbricataria, Mesalia sulcifera, Conus deperditus, Pleurotoma (Surcula) attenuata, Melongena minax, Strepsidura turgida, Voluta nodosa, V. spinosa, Ancilla buccinoides.

*Fossils of the Barton Beds**Protozoa.*

Nummulites elegans.

Echinoderma.

Schizaster d'Urbani.

Lamellibranchs.

Cardita sulcata, Crassatellites sulcatus, Cardium porulosum, Corbula pisum, C. ficus, Pecten (Chlamys) reconditus, Pectunculus deletus, Chama squamosa.

Gastropoda. *Turritella imbricata*, *Rostellaria* (*Hippochrenes*) *ampla*, *Rimella rimosa*, *Conorbis dormitor*, *Murex asper*, *Typhis pungens*, *Fusus porrectus*, *Clavella longæva*, *Buccinofusus regularis*, *Pleurotoma* (*Surcula*) *rostrata*, *Cassidaria nodosa*, *Xenophora agglutinans*, *Olivella Branderi*, *Voluta athleta*, *V. luctatrix*.

B. BRITISH EOCENE DEPOSITS

The present restricted extent of the Eocene deposits in England and their separation into two basins are due to the upheaval and

Fig. 180.—FOSSILS OF THE BRACKLESHAM AND BARTON BEDS.

- a. *Voluta athleta*.
- b. *Conus deperditus*.
- c. *Xenophora agglutinans*.

- d. *Olivella Branderi*.
- e. *Ancilla buccinoides*.
- f. *Cardita planicosta*.

disturbance which took place in Miocene time, when lateral pressure from the south established a series of east and west flexures; and as the Palæogene deposits have been removed from the anticlinals, the parts which remain occupy two synclinal areas, *i.e.* the London and the Hampshire basins.

A glance at any geological map will show the extent of the Palæogene Beds in these two areas. The London basin extends from Hungerford in Berkshire to Reculvers in Kent, and its northern boundary passes from Reading through the counties of

Buckingham, Hertford, and Essex to near Framlingham in Suffolk, where the influence of the syncline dies out and the boundary line then runs northward to the west of Yarmouth. Its length from Hungerford to Reculvers is about 120 miles, and its width from Sudbury to Canterbury is nearly 60 miles, but this is probably less than half its actual extent, the rest of the basin being concealed by the waters of the North Sea.

The Hampshire basin is much smaller, and lies in a trough between the anticlinal axis of Winchester on the north and the monoclinal of Purbeck and the Isle of Wight on the south, and its extreme width is, therefore, only 25 miles, while its length from Dorchester to near Worthing in Sussex is about 60 miles, with an outlier at Newhaven nearly 20 miles farther east. There is evidence, however, of the original extension of the Eocene through Dorset and East Devon.

In Ireland freshwater beds of Eocene age are interstratified with

Fig. 181.—DIAGRAM TO ILLUSTRATE THE PRE-TERTIARY EROSION OF THE CHALK.

b, b. Upper Chalk.

a, a. Base of Upper Chalk.

L. London Clay.

W. Woolwich Beds.

T. Thanet Beds.

the great sheets of basaltic lava which cover so large an area in Antrim and Derry. In Scotland a similar set of lavas, also with intercalated freshwater beds, attains a great thickness in the islands of the Inner Hebrides (Mull, Skye, etc.).

In Britain there is a decided unconformity between the Cretaceous and Palæogene Systems, a break which indicates a considerable lapse of time and a great change of physical and geographical conditions. We have seen that there are deposits in France and Belgium which partially bridge over this gap, and similar deposits may also have been formed in the British area, but if so, they were destroyed before the deposition of our lowest Eocene strata. It is now certain that large tracts of the Upper Chalk have been removed from certain areas either before or during the formation of the earlier Eocenes, for we cannot doubt that the higher parts of the Chalk were originally continuous from Hampshire to Norfolk, yet they do not now exist under the London basin, and consequently the Upper Chalk, which in Sussex

is at least 750 feet thick, and in Norfolk is probably 1000 feet, has only a thickness of from 250 to 300 feet beneath the valley of the Thames. Moreover, where the Upper Chalk is thinnest, the London Eocenes are thickest, and there can be no doubt that these Eocenes were deposited in a broad and deep trough, which had been excavated out of the Upper Chalk. The relation of this trough to the general surface of the Chalk is indicated in the diagram, Fig. 181.

The following are the divisions of the Eocene Series now recognised in the London and Hampshire basins. They can be grouped into Lower and Upper Eocene, but the creation of a Middle Eocene is quite unnecessary.

London Basin.		Hampshire Basin (Isle of Wight).	
	Feet.		Feet.
Upper	{ ? Wanting.	Barton Beds .	340 to 360
	{ Bracklesham Sands about 200	{ Bracklesham and	
	ham { Clays „ 60	{ Bournemouth Beds	555 to 583
	{ Bagshot Beds . „ 150	Bagshot Beds .	243 to 98
Lower	{ London Clay . „ 400	London Clay .	230 to 320
	{ Woolwich and		
	{ Reading Beds „ 80	Reading Beds .	80 to 160
	{ Thanet Beds . „ 80	Absent	
About 970		1450 to 1520	

It will be seen that the Lower Eocene is more fully developed in the London basin than in Hampshire and includes the lowest division (Thanet Beds), which does not occur in Hampshire. On the other hand, the Upper Eocene is thin and incomplete near London, but is fully developed in the Hampshire basin.

The Thanet Beds, as their name implies, are well developed in the Isle of Thanet. They consist mainly of pale-coloured sands, the lowest part being always argillaceous and full of dark-green glauconitic grains, while at the base, and resting on the Chalk, there is invariably a layer of *unworn* green-coated flints. These flints show no signs of attrition, and are believed to have been derived directly from the underlying chalk, not by mechanical erosion, but by chemical solution; carbonated rain-water percolating through the sands and dissolving the subjacent chalk, but leaving the insoluble flints behind; so that a layer of these nodules has gradually accumulated at the base of the sand, but was not there when the sands were originally deposited. This supposition is confirmed by the fact that no fossils occur in this basement-bed, whereas if the flints had ever lain on a sea-bottom small oysters, serpulæ, etc., would certainly have fixed themselves on to such favourable surfaces for attachment.

In East Kent the greater part of this stage consists of greenish sandy marl (50 or 60 feet), overlain by sharp greenish-grey sand

Fig. 182.—SECTION ALONG THE CLIFF ALONG THE NORTH SIDE OF PEGWELL BAY, KENT (by H. Burrows and R. Holland).

- A. Loam (Pleistocene).
- B. Yellow and buff sands.
- C. Grey and buff sands.

- D. Dark-greenish sandy marl.
- E. Dark-grey shaly marl.

- F. Grey, green, and yellow sandy marl.

- G. Layer of green-coated flints.
- H. Upper Chalk.

N.B.—The Thanet Beds comprise G to H inclusive.

Fig. 183.—SECTION FROM PINNER TO HAMPSHEAD (by J. L. Lobley). Distance 12 miles.

- 6. River gravel.
- 5. Plateau gravels.

- 4. Bagshot Sands.
- 3'. Upper sandy London Clay.
- 3. London Clay.

- 2. Woolwich and Reading Beds.
- 1. Upper Chalk.

(30 to 40 feet), and both beds contain many fossils (see p. 529); the best exposure is in the cliffs of Pegwell Bay near Ramsgate, and this is illustrated in Fig. 182. It is also seen at Reculvers on the north coast of Kent. Westward the sandy marl passes into fine soft pale-green or buff sand (argillaceous at the base), while the upper sands appear to thin out, so that in the west of Kent the whole is not more than 50 feet thick; this type of the Thanet Beds is well exposed in the pits near Woolwich and Charlton, but contains no fossils. Thence the outcrop runs by Crayford and Croydon to Epsom, where the sands are only 15 feet thick, thinning out entirely near Ashstead.¹

The Thanet Beds thin northward as well as westward, for though well-sections at Chelmsford and Braintree show them to be about 30 feet thick, at their outcrop near Sudbury they are only 16 feet, and they thin out to the west near Gestingthorpe.

The Woolwich, Reading, and Oldhaven Beds.—These form a much more variable group, and exhibit three different facies as they are traced from east to west:—(1) the marine type, consisting of grey sands with marine shells, is only found in East Kent; (2) the estuarine or *Woolwich* type occurs in West Kent and East Surrey, and consists of sands, clays, and pebble beds, with estuarine and freshwater shells; (3) the *Reading* type of the western and northern tracts consists of unfossiliferous variegated plastic clays and bright-coloured sands.

Overlying the marine and estuarine beds of the Woolwich Group in Kent and Surrey are pebbly sands and pebble beds, from 10 to 50 feet thick, which are termed the *Oldhaven or Blackheath Beds* by Mr. Whitaker, and are grouped by him as a third division of the Lower London Tertiaries. Their stratigraphical extent, however, is not great, and their palæontological importance is small, so that they hardly seem entitled to rank as a primary division.

The coast near Reculvers in Kent furnishes a good section of the marine type of this group, and is as follows:—

	Feet.
<i>Oldhaven Beds.</i> —Grey and buff sands, hardened in places into a ferruginous sandstone; a layer of pebbles at base	20
<i>Woolwich Beds.</i> —Pale-grey sand with sharks' teeth, <i>Corbula regulbiensis</i> , <i>Protocardium Laytoni</i> , <i>Cyprina Morrisi</i> , etc.	25

Near Milton estuarine beds come in near the middle of the Woolwich Beds, and at Upnor on the Medway there are 6 feet of clay with brackish-water fossils intercalated in the pale-grey sands.

At Woolwich the greater part of the beds are estuarine clays and sands, in which *Melania inquinata*, *Potamides funatus*, and *Cyrena cuneiformis* are common fossils. Resting on an eroded

Fig. 184.—SECTION FROM NEAR ALDERSHOT TO THE RIVER WEY NEAR FARNHAM IN SURREY (by W. Whitaker).

- a. Gravel.
- b. Barton Beds.
- c. Bracklesham Beds.
- d. Bagshot Sands.
- e. London Clay.
- f. Reading Beds.
- g. Chalk.
- h. Greensand } Selbournian.
- i. Gault }
- k. Vectian.

Fig. 185.—SECTION ACROSS THE WESTERN END OF THE ISLE OF WIGHT BEHIND ALUM BAY (by H. W. Bristow).

- 10. Bembridge limestone.
- 9. Lower Bembridge Beds.
- 8. Headon Beds.
- 7. Barton Sand.
- 6. Barton Clay.
- 5. Bracklesham Beds.
- 4. Bagshot Sands.
- 3. London Clay.
- 2. Reading Beds.
- 11. Pleistocene gravel.
- 1. Upper Chalk.

surface of the Woolwich Sands is a mass of pebbles in a sandy matrix, taking the place of the Oldhaven Beds and often called the Blackheath Beds.

The Blackheath Beds do not extend west of Croydon, and are not found along the northern edge of the London basin. The pebbles composing them are all well-worn and rounded flints without any subangular pebbles such as occur on our shingle beaches; hence Mr. Whitaker concludes that they were not laid down in beaches, but were deposited by strong currents at some little distance from the shore, and his view is confirmed by the frequency of current bedding.

Beds of mottled plastic clay begin to appear in West Kent near the base, and these increase westward through Surrey, the shell-bearing beds gradually dying out, till in Hampshire and Berkshire they consist entirely of mottled clays, in tints of red, yellow, grey, purple, and green, associated with beds of red, yellow, and white sand. These are known as the Reading Beds, and marine fossils only occur in the basement-bed, the only fossils in the clays being leaves of plants. Near Reading the group consists of:—

	Feet.
Mottled clays	40 to 50
Yellow and white sands	20 to 30
Bottom bed with marine fossils	5 to 8

Beds of the same (Reading) type range along the northern lip of the basin through Herts and Essex, but include some pebble beds which are occasionally concreted into the kind of conglomerate known as "plum-pudding stone."

They recur in the Hampshire basin, where they consist almost entirely of bright red and white mottled clays with several layers of brown sand, one of these being at the base and resting on the Chalk. No fossils except fragments of plants have yet been found in these clays, and they do not therefore seem to be of marine origin. Their thickness in Whitecliff Bay is 163 feet, at Alum Bay 84 feet, and they are still from 70 to 80 feet thick in Dorset near Bere Regis. Near Dorchester they include beds of sand and of subangular gravel consisting of Cretaceous flints and cherts.

The London Clay occupies broad areas both on the north and south side of the Thames Valley. It is of much more uniform composition than the lower group, the mass of it consisting of stiff bluish clay with layers of septarian nodules. The surface colour of the clay is generally brown, but this is due to the oxidation of the iron it contains by exposure to the weather; its normal tint in deep wells and borings is a bluish-grey colour.

The basement-bed is of a different character to the rest, consisting of brown, grey, or greenish sand and sandy clay, in which

are scattered many rolled flint pebbles; these pebbles are always black, and sometimes have the remarkable peculiarity of falling into fragments when tapped by a hammer, for though to the eye they seem compact, they are really traversed by a multitude of invisible cracks. This basement-bed is generally from 6 to 12 feet thick, and often contains fossils, of which the chief are *Aporrhais Sowerbyi*, *Calyptra aperta* (= *trochiformis*), *Pitaria obliqua*, *Panopæa intermedia*, *Pectunculus brevirostris*, and *Ditrupa plana*.

The thickness of the London Clay near London is between 400 and 500 feet, but it thins gradually westward to about 270 at Wokingham, 50 near Newbury and Hungerford, and only 15 in the outlier of Great Bedwin in Wiltshire.

Fossils are not common throughout the London Clay, but sometimes occur in great profusion, especially where beds of sandy clay occur. The cliffs of the Isle of Sheppey are noted for the fossils they yield; plant remains are there especially abundant, and bones of birds, turtles, and snakes have also been found.

In the Hampshire basin, with the exception of an outlier at Newhaven, the most easterly exposure of this division in this area is at Bognor in Sussex, where beds of clay and calcareous sandstone, highly fossiliferous, are exposed on the shore, and are supposed to belong to the lower part of the London Clay.

Borings at Portsmouth Dockyard below the summit of the formation proved a thickness of 290 feet, and exposures made in extending that dockyard from 1868 to 1870 were described by Mr. Meyer,² who found the clay divisible into three parts, each commencing with a layer of pebbles and passing upward from stiff clays into sandy clays. The lowest zone is about 100 feet thick, the middle zone has a thickness of 134 feet, and the sandy beds in the upper part of this yielded many fossils. The uppermost zone consists mainly of clays containing *Cyprina planata*, *Pholadomya margaritacea*, *Rostellaria lucida*, and other species.

In the Isle of Wight the London Clay is about 320 feet thick at Whitecliff Bay, but only 230 at Alum Bay.³ At neither place are many fossils to be found, but at Whitecliff the higher part contains *Panopæa intermedia*, *Cyprina planata*, *Callista tenuistriata*, and *Pinna affinis*. At 262 feet from the base there is a layer of black flint pebbles, and above this are sandy and laminated clays. In Dorset the London Clay consists chiefly of brown sandy loam with seams of sandy ironstone and a bed of flint pebbles at the base. Its thickness in the Purbeck district is from 70 to 80 feet, but it thins westward, and is finally overlapped by the Bagshot Beds near Dorchester.

Bagshot Beds.—In the London Basin these beds occupy a

much smaller space than the London Clay because they have been removed from the greater part of its surface by subsequent detrition and erosion, but there is good reason to believe that they were not only coextensive with the London Clay but spread beyond its original borders. The chief remaining tract of Bagshot Sand is an area about 24 miles in length with a breadth of about 10 or 12 miles, and occupying parts of Berkshire, Hampshire, and Surrey. Aldershot, Farnborough, Bagshot, Wokingham, Ascot, and Cobham all lie within this area. Westward there are several outlying tracts, some large and some small; and north of the Thames in Middlesex are three small outliers capping Harrow, Hampstead, and Highgate Hills (see Fig. 183).

The extreme thickness of these sands in the Bagshot and Farnborough country is from 130 to 150 feet. Westward at Ramsdell, in the outlier between Basingstoke and the valley of the Kennet, there is a bed of brown clay very like London Clay, and 30 feet thick, in the lower part of the Bagshot Sand.

In the Hampshire Basin the Bagshot Beds consist of bright yellow and white sands with bands of grey laminated sand and clay and (in the upper part) layers of white pipeclay, which contain leaves and stalks of plants belonging to the genera *Aralia*, *Cassalpinia*, *Comptonia*, *Dryandra*, *Ficus*, *Laurus*, *Quercus*, and other Dicotyledons. Ferns are rare in the Isle of Wight, but *Chrysodium lauzeanum* abounds at Stndland in Dorset. This flora indicates a warmer climate than that of the Reading Beds.

There is much difference of opinion as to the thickness assignable to these beds in the Alum Bay section (Fig. 185); the Geological Survey classes all the sands and clays which do not yield marine fossils as Lower Bagshot, and these amount to 662 feet. Mr. J. S. Gardner,⁴ however, has shown that the special Bagshot flora does not occur above the pipeclays, and that the higher beds at Bournemouth contain a very different flora. He also thought that the lower part of these sands replaced the upper part of the London Clay, but if the latter is restricted to 233 feet, the Bagshot Sands will have a thickness of 243 feet at Alum Bay, and decrease eastward till they are only 98 feet in Whitecliff Bay.

At Stndland and Corfe in Dorset the Bagshot Beds have the same facies, but westward they pass into coarse subangular gravels, which near Dorchester overlap both London Clay and Reading Beds so as to rest directly on the Chalk. These gravels contain pebbles of Cretaceous flint and chert, Purbeck marble, with many of quartz and of Palæozoic rocks probably derived from the Permian breccias of Devonshire. Still farther west they overstep the Chalk and rest on the Selbornian Sands.

The Bracklesham Beds.—In the London basin the lower part of this group consists of brown laminated clays, overlain by dark-green clayey sand from 12 to 20 feet thick, and succeeded by a variable set of greenish sands with bands of clay, the total thickness varying from 40 to 80 feet. These beds have yielded a few fossils, *Fusus longævus*, *Turritella sulcifera*, *Cardita planicosta*, *Pecten corneus*, *Ostrea flabellula*, *Corbula striata*, *Nummulites lævigatus*, and many fish teeth, *Lamna obliqua*, *Carcharodon auriculatus*, etc.

Above the clays is a mass of sands formerly called the Upper Bagshot Sand, but now referred to the Bracklesham Group, and possibly representing the Boscombe Sands mentioned below. At the base is a layer of small flint-pebbles, and the fine yellow and white sands which succeed are the highest Eocene Beds that occur in the London basin. Their thickness appears to be over 200 feet, for in a boring at the Albert Asylum, Bagshot, their depth proved to be 226 feet.⁵ These sands contain in the upper part blocks of white saccharoid sandstone, which, when weathered out, are known as "grey-wethers"; they are sometimes 10 to 14 feet long, and 3 or 4 deep, and they often enclose flint pebbles. Organic remains are rare, but here and there are casts of shells, and about forty-eight species were obtained by Mr. Monckton from the Tunnel Hill cutting near Pirbright on the South-Western Railway. Among these the commonest were *Rimella rimosa*, *Natica patula*, *Turritella imbricaturia*, *Ostrea flabellula*, *Pecten reconditus*, *Cardita sulcata*, *Lucina mitis*, *Tellina scalaroides*, and *Corbula pisum*.

These beds received their name from Bracklesham Bay in Sussex, where they contain marine shells throughout their extent along the shore, but there are no cliffs in which they can be measured.

The section in Whitecliff Bay exhibits the same marine type, and has been described in detail by the Rev. O. Fisher,⁶ who divided the group into four portions. Mr. H. Keeping has since been able to fix the limit between the Bracklesham and Barton Beds more exactly, and finds it to be about 70 feet lower than where Mr. Fisher placed it. Making this alteration, the thicknesses of the several parts are as follows :—

	Feet.
A. Green and blue clays with a bed of sand about 52 feet from the base, <i>Nummulites variolaris</i> , <i>Pecten corneus</i> , <i>Corbula pisum</i> , <i>Pleurotoma plebeia</i> , etc.	182
B. Yellow sands and sandy clays, <i>Num. variolaris</i>	27
C. Sandy clays and green sands, <i>Num. lævigatus</i> , <i>Sanguinolaria Hollowaysi</i> , <i>Voluta spinosa</i> , etc.	123
D. Laminated clays and green sands with a bed of pebbles at the base, <i>Num. lævigatus</i> and a few other fossils	251
	<hr/> 583

It will be noticed that C and D form a zone of *Nummulites laevigatus*, while A and B are characterised by *Num. variolaris*.

On reaching Alnm Bay we find that the greater part of this group is represented by unfossiliferous sands and clays, probably estuarine beds, and that marine shells are only found in the uppermost 157 feet, which answer to Mr. Fisher's group A. The lower beds were formerly relegated to the Lower Bagshot, but their true position has been determined by Mr. Gardner, who has compared them bed by bed with those of the opposite cliffs of Hampshire.⁷ Their thickness is 398 feet, making a total of 555 feet.

The succession of the Bournemouth and Boscombe Beds has been carefully worked out by Mr. Gardner, who gives it as follows:—

	Feet.
6. Dark sandy clays with pebbles at base	14
5. Highcliff Sands, white and without fossils	31
4. Hengistbury Clays, with septaria containing sharks' teeth	57
3. Boscombe Sands, of various colours containing pebbles	140
2. Bournemouth marine beds, with plants and marine shells	50
1. Bournemouth freshwater beds, with plant remains only	400

About 590

The Freshwater Beds consist largely of sand with occasional bands of clay in which leaves are abundant, especially those of *Salix* (willow), *Triarteia* (a palm), *Sequoia Coutssæ*, *Araucaria*, *Eucalyptus*, and the ferns *Osmunda*, *Polypodium* and *Acrostichum*.

The marine beds are a similar set of deposits, but among the plants are *Palmacites* (a cactus), *Dryandra*, and the fruits of the *Nipa* palm.

Barton Beds.—The most careful study of these beds is the memoir by Messrs. Gardner, Keeping, and Monckton,⁸ on which the following account is based. They divide the stage into three parts, which they call Lower, Middle, and Upper Barton, but the Geological Survey divide it into the Barton Clay and the Barton Sands, which is in some ways a more convenient division.

According to these authors the thicknesses of their divisions at the three principal sections are as follows:—

	Barton.	Alum Bay.	Whitecliff.
Barton Sands or Upper Barton	90	114	221 feet.
Barton Clay { Middle Barton	53	167	92 „
{ Lower Barton	49	57	55 „
	192	338	368 feet.

The Lower Barton has at its base a thin zone of green sandy

clay in which *Nummulites elegans* (var. *prestwichiana*) is common, and serves to define the Barton from the underlying Bracklesham Beds. Above are grey clays and sands containing *Voluta athleta*, *Cassia ambigua*, *Rimella bartonensis*, and *Cominella canaliculata*.

The Middle Barton, or Barton Clay proper, consists mainly of grey and brown clays with bands of septaria, and its prevalent fossils are *Voluta luctatrix*, *V. ambigua*, *Rostellaria ampla*, *Murex minax*, *Clavella longeva*, and *Crassatella sulcata*. At Alum Bay there is a remarkable increase in the thickness of this group, and the upper 70 feet consist of yellowish sandy clays with many small Mollusca, no such beds being seen at Whitecliff.

The Barton Sands at Barton present the following succession :—

	Feet.
4. White and yellow sands with <i>Potamides concavus</i> , <i>Olivella Branderi</i> , and <i>Melania hordeacea</i>	20
3. Dark-grey sandy clay with <i>Olivella Branderi</i> and other shells	26
2. White sand without fossils	25
1. Bluish-grey clayey sand (the <i>Chama</i> Bed) with <i>Chama squamosa</i> , <i>Terebratulula bisinuata</i> , <i>Terrebellum sopitum</i> , <i>Voluta costata</i> , <i>V. humerosa</i> , and <i>Conus scabriculus</i>	18

At Alum Bay the *Chama* Bed is rarely exposed, and the higher beds are represented by a mass of yellow and white sand from 90 to 100 feet thick, which has been largely dug for glass-making. These sands are sometimes called the Headon Hill Sands, and at the east end of the island they thicken to 206 feet, and the *Chama* Bed is seen below them with a thickness of 15 feet.

C. THE REGION OF VOLCANIC ACTIVITY

The northern parts of the British Isles were a scene of remarkable volcanic activity throughout a large portion, if not the whole of Eocene time, and evidences of this activity are found not only in the vast lava-flows above mentioned but in lava-filled fissures of great length. The region over which such phenomena have been found embraces the north of England, the north of Ireland, and the whole of Southern and Western Scotland, and it must also have included the area of the adjoining seas as far south as Anglesey, as far west as St. Kilda, and as far north as the Faroe Islands—a total area of about 50,000 square miles. Its history has been written by Sir Archibald Geikie⁹ and Mr. A. Harker,¹⁰ and the following is an epitome of it.

This great development of volcanic action seems to have coincided with a general elevation of the region above indicated, as if it had been pushed upward by the accumulation of a vast sea

of liquid lava beneath it. Whether as cause or coincidence, it seems certain that great horizontal tension arose which started a series of fissures, these running generally from north-west to south-east, and sometimes extending for 50, 60, or even 100 miles. Into these fissures welled up the liquid rock which has consolidated into basalt, and where they reached the surface the lava welled out in vast streams like those of modern Iceland, forming the great basalt plateaux of Antrim and the west of Scotland.

This process of dyke-making and the outpouring of lava-floods was repeated again and again, till on the great plain or plateau which bordered the west of Scotland the lavas accumulated to a depth of several thousand feet. In some places 3000 feet of them still remain, and we know not how great a thickness has been removed. Here and there they filled up and obliterated river-channels like those in the island of Mull.

After the building up of these plateaus another episode took place. Large bodies of a basic magma were pushed into and through the plateau basalts and consolidated into huge domes of gabbro, troctolite, and other such coarse-grained rocks, but whether they ever extruded matter at the surface cannot be known, because the summits of the bosses are removed.

The next phase was the protrusion of material from a different magma, which has consolidated into acid rocks of various kinds, from glassy obsidians and rhyolites to granophyres and a rock of granitic character. These now form conical hills which resemble in some respects the trachytic hills of Auvergne.

The last phase was a second formation of fissures, producing another system of basic dykes which traverse all the previously formed rocks, cutting not only the older dykes but the great masses of gabbro and granophyre. Whether they poured lava to the surface is not known, and whether the formation was the final episode is not quite certain, for there is also a series of acid dykes which traverse all the older volcanics and do not appear to be cut by the later basic dykes. The age of these later basic and acid dykes is also uncertain; they may be Oligocene, or even Miocene; but whenever vulcanism did cease the whole region began to sink down again, and at the present time great parts lie below the sea.

Ireland.—The largest remaining portion of the great lava plains is the basaltic plateau of Ulster (Antrim and Derry) (see Fig. 186), which has an area of about 2000 square miles. This plateau presents steep escarpments on all sides, but the ground falls towards a central trough in which lie Lough Neagh and the valley of the river Bann. The component lavas are almost entirely basaltic, but they are divisible into a lower and upper series. The

Fig. 186.—DIAGRAMMATIC SECTION ACROSS THE PLATEAU OF ANTRIM. Distance about 40 miles.

- e.* Eocene lava-flows (basalts).
a. Palaeozoic rocks.
x. Sea-level.
c. Patches of Lias and Rhaetic Beds.
d. Triassic marls and sandstones.

Fig. 187.—DIAGRAMMATIC VIEW OF ARDTUN HEAD (by J. S. Gardner). Distance about 1½ miles.

- a.* Intrusive sill of basalt.
b, c. Basaltic lava-flows.
e. Interbedded fluviatile deposits.
d. Supposed dyke.

lower lavas rest on an irregular floor of older rock, the substratum being in most places Chalk, but between it and the lowest lava-flow there is always a bed of brown ferruginous clay full of flints. These lower lavas are mostly massive or amygdaloidal basalts, and their combined thickness is from 400 to 500 feet.

Between the two series of lavas there is a break which appears to have coincided with the plutonic phase above mentioned, when the intrusive masses of gabbro and granite were formed. In Antrim this is marked by a band of stratified beds consisting of brown and red clays with layers of lignite, beds of pisolitic iron-ore (bauxite), of volcanic sand, and conglomerates composed of pebbles of rhyolite and basalt. Over these beds are piled thick and extensive sheets of basalt and dolerite, which at Sleamish have a thickness of about 600 feet. The well-known columnar basalt at the Giant's Causeway is one of these sheets and overlies a bed of bole or laterite.

At Glenarm and at Ballypalady near Templepatrick there are thick deposits of iron-ore, the lower bed being a compact ferruginous earth known as lithomarge, which is sometimes 40 feet thick, and is overlain by pisolitic ore, and these occur some 600 feet from the base, and 400 feet from the top of the basaltic formation. At Glenarm they are associated with sandy clays and pebble beds, which enclose a seam containing well-preserved leaves and plant remains. Among these *Daphnogene Kanei*, *Sequoia Coutssie*, *Macclintockia Lyelli*, and leaves of *Platanus*, *Quercus*, and *Rhamnus* have been identified by Baily. Mr. J. S. Gardner considers the flora to be of early Eocene age, not Miocene as previously supposed.¹¹

Scotland.—The basaltic plateau of Ulster is only a portion of a very extensive tract of similar materials which has been largely broken up and destroyed, but must have originally stretched northward to the west coast of Scotland, where other large remnants of it are found in the Isles of Mull, Eigg, Rum, Skye, and Raasey. In the present connection the most important Scottish locality is the promontory of Ardtun Head in the south-western part of Mull. Here beds of gravel sand and shaly clay are intercalated between two great sheets of basalt and have yielded many plant remains. The beds were first investigated by the late Duke of Argyll, but more recently by Mr. J. S. Gardner,¹² from whose account the following is taken, together with the illustrative section, Fig. 187.

The sedimentary rocks appear along the seaward face of the headland for a distance of rather more than a mile, and the succession seen in one of the quarries is as follows :—

	Feet.
Rudely columnar basalt	10
Bedded sandstone	8
Indurated gravel of flints and lava-fragments	7
Indurated dark-coloured mud with ferns	1
Black crumbly shale full of leaves	2½
Hard gravelly sand resting on basalt	2

At other points there are several beds of clay or shale which contain leaves, and similar beds also occur near Carsaig. The plant remains include a fern (*Onoclea hebridica*) and an *Equisetum*, many Gymnosperms, such as *Ginkgo*, *Podocarpus*, *Taxus*, and *Sequoia*. Dicotyledons are abundant and include leaves of *Platanus hebridicus*, *Populus arctica*, *Cornus hyperborea*, *Boehmeria antiqua*, and leaves like those of *Corylus*, *Laurus*, and *Rhamnus*. Mr. Gardner considered the flora to be more like a late Cretaceous than a Tertiary one, but accepting its probable connection with the Antrim area, was inclined to regard it as of very early Eocene age, and not newer than the time of the Thanet Beds.

That the island of Arran was included in the area of Tertiary volcanic activity has long been suspected, but it was only in 1899 that absolute proof of the fact was obtained.¹³ No remnants of basaltic lava-flows remain on the island, but all the southern part of it is seamed with basalt dykes, and it is very probable that many of these belong to the earlier dyke-system, and that surface eruptions proceeded from them; all traces of such eruptions have, however, been destroyed.

The most remarkable feature of the island is the large volcanic vent which occupies the central district around Glen Craigagh, between Brodick and Machrie Bays. The complex of rocks by which this vent is now filled has an oval form about 3½ miles in length by 3 in breadth; its central portion (over 2 miles in diameter) is composed of a breccia or agglomerate, consisting largely of fragments of sedimentary rocks mixed with a smaller quantity of igneous rock-fragments. This area is surrounded by a ring of intrusive igneous rocks, which are chiefly granites, granophyres, and felspathic rocks.

Some of the rock-fragments in the central agglomerate are Old Red Sandstone, and have been blown up from below; others are large blocks of Trias, Rhætic, Lias, and Chalk, which must have fallen into the vent from above, and testify to the existence of a former covering of Jurassic and Cretaceous strata of which all other traces have been destroyed. As remarked by Sir A. Geikie in the *Summary of Progress* for 1900 (p. 124), "the explosion was thus certainly later than the Upper Cretaceous period and may consequently be referred to older Tertiary time. The fixing of the

age of this vent carries with it the determination of the age of all the associated eruptive rocks. There can now be no room to doubt that the granites, quartz-porphyrines, felsites, pitchstones, diorites, diabases, and basalts are all a connected series of eruptive masses, coeval with the similar assemblages in Antrim, the Inner Hebrides, and St. Kilda."

D. CONTINENTAL EQUIVALENTS

The Eocene area of Belgium may be regarded as a continuation of the London basin, for the two are doubtless in actual connection beneath the North Sea. Again, the deposits of the Paris basin present such a great resemblance to those of the Hampshire basin that they can be correlated without much difficulty, and were doubtless formed within the same area of deposition. In the south of France, however, and in the south of Europe generally, the Eocene Series exhibits a very different facies, consisting largely of hard foraminiferal limestones full of *Nummulites*, *Operculina*, and *Alveolina*, and generally known as Nummulite limestones; with these are calcareous sandstones containing many large shells, reef-building corals, and Echinoderms of many species.

The accompanying table shows the divisions recognised in the Eocene Series of Belgium and France, and their correlation with those of England.

England.	Belgium.	France.	
Barton Beds.	Wemmelian, sands.	Bartonian, sands and limestones.	Parisian, 250 feet.
Bracklesham Beds.	Bruxellian, sands and sandstones.	Lutétian (Calcaire Grossier), limestones.	
Bagshot Sands, London Clay.	Sables de Mons, Argile de Flandres.	Yprésian, sands only.	
Woolwich and Reading Beds.	Landenian (freshwater beds).	Sparnacian (freshwater beds).	Suessonian, about 350 feet.
Thanet Beds.	Heersian, sands and marls.	Thanetian, Marine sands.	
—	Montian, limestones.	Montian, limestone and marl.	

The name *Montian* is taken from Mons in Belgium, *Thanetian* from our Isle of Thanet, *Sparnacian* from Eparnay (Sparnacum), *Yprésian* from Ypres in Belgium, *Lutétian* from Lutetia the Roman name of Paris, and *Wemmelian* from Wemmel in Belgium.

From the above table it will be seen that deposition began earlier both in Belgium and France than in the English area, the Montian Beds forming a kind of link between the Cretaceous and Eocene Series.

1. Belgium

Montian.—The beds referred to this stage have a thickness of from 200 to 300 feet, and the Geological Survey of Belgium now recognises three subdivisions which in descending order are:—

3. Freshwater beds with *Physa montensis*.
2. The limestone of Mons (and Upper Tuffeau of Ciply).
1. The *Cerithium* limestone and basal conglomerate.

The basal conglomerate lies unconformably on the higher Cretaceous strata, and the *Cerithium* limestone is so called from containing a large *Cerithium* (*C. Corneti*). The Mons limestone is a rough yellowish friable rock composed mainly of shell-fragments, Foraminifera, and calcareous algæ. It contains a large fauna, consisting mainly of Gastropoda, with a fair number of Lamelli-branches and a few Echinoderms; *Cerithium montense*, *Cer. inopinatum*, *Turritella montensis*, *Mitra Devalquei*, *Pseudoliva robusta*, *Cidaris distincta*, *Cassidulus elongatus*, and *Echinanthus Corneti* are characteristic species, and there are a number of freshwater and terrestrial shells which have been washed into the deposit from neighbouring land. No Ammonites or true Belemnites occur, but the latter are represented by two species of *Beloptera*.

The Heersian or Lower Landenian of Mourlon consists of glauconitic sands passing laterally into soft sandstone or sandy marl. Its fauna is marine and like that of our Thanet Beds, but near Gelinden the sands include a band of white marl containing the remains of an early Eocene flora (*Osmunda eocenica*, *Laurus Omali*, *Cinnamomum Sezannense*, etc.). The total thickness of the Heersian is about 60 feet.

Landenian.—This group is of freshwater origin and resembles our Woolwich Beds, consisting of sands and marls with beds of shaly lignite. The thickness is only from 30 to 50 feet.

Yprésian.—This stage falls naturally into two parts, of which the lower (Argile de Flandres) is a continuation of the London Clay. In a boring at Ostende its thickness was found to be 460 feet, but it thins eastward just as the London Clay thins westward. Fossils are scarce in this clay, but it is overlain by sands and

sandy clays which yield *Nummulites planulatus*, *Turritella edita*, *Pectunculus decussatus* and other fossils, and are from 100 to 150 feet thick. Of about the same age are the sands of Mount Panisel near Mons and those of Oeltre in Flanders, which contain *Pinna margaritacea*, *Rostellaria fissurella*, *Turritella edita*, and *Cardita planicosta*.

Bruxellian, better latinised as *Brussellian*; this name is restricted by Belgian geologists to the lower part of a mass of sand and sandstone which corresponds to our Bracklesham Beds. Fossils are abundant in these sands, but generally in a bad state of preservation, except sharks' teeth such as *Lamna elegans*, *Otodus macrotus*, *Galocerdo minor*, *Enchodus Blecheri*, and *Myliobates toliapicus*. The fruits of the Nipa palm (*Nipadites Burtini*) are also common. The higher sands are known as *Laekinian* and are characterised by *Nummulites Heberti*, *N. variolaria*, and *Ditrupea strangulata*. The total thickness is not more than 180 feet.

The **Wemmelian** has a basement-bed of sandy gravel containing *Nummulites variolaris*, overlain by sands and a band of sandy glauconitic clay. In these beds *Num. wemmeliensis* is a characteristic species, with *Turritella sulcifera*, *Voluta elevata*, *Cardium porolosum*, *Tellina rostralis*, and *Pectunculus pulvinatus*. The thickness of these beds varies from about 50 feet near Brussels to 170 at Malines, and over 200 in a boring at Anvers.

2. The Paris Basin

Montian.—This is not so well developed in France as it is in Belgium, because it has been deeply eroded in many places before the deposition of the succeeding Thanet sands. It varies, consequently, in thickness from 6 feet at Meudon to 162 at Mont Aimé near Vertus.¹⁴ Typically it is a yellow granular limestone, partly oolitic and partly composed of shell debris. It is probably somewhat older than the limestone of Mons, for it contains *Nautilus danicus*, but with this are large *Cerithia*, *Turritella montensis*, *Pseudoliva robusta*, *Fasciolaria prima*, *Lima Caroli*, *Corbis multilamellosa*, and other Montian species. At Meudon it is succeeded by white marls which are partly of marine and partly of freshwater origin. Limestones of the same age occur in the Pays de Bray at Vigny, and at Laversine near Beauvais.

Thanetian.—Glauconitic sands which appear to be about the age of our Thanet Beds are found all along the northern and eastern borders of the Paris basin, and as a rule they rest directly on the Chalk. Such are the sands of Watten and St. Omer near Calais, which are characterised by *Cyprina planata* and are often indurated by a siliceous cement into a stone known as *tuffeau*,

resembling gaize or malmstone and containing diatoms and sponge spicules. Farther south in the Aisne are the sands of La Fère and of Châlons-sur-Vesle, which seem to be of the same age, while westward near Beauvais are the sands of Bracheux, containing *Cyprina planata*, *Ostrea bellovacina*, *Pectunculus terebratularis*, etc., a fauna which is classed as Thanetian by the majority of French geologists, but as Sparnacian by Professor Prestwich.¹⁵ None of these sands extend so far as Paris.

Sparnacian.—This group corresponds very closely to our Woolwich and Reading Beds. Near Paris it consists principally of plastic clays, but at the base is a conglomerate with bones of mammals and birds, overlain by laminated clay containing *Physa*, *Viviparus*, and *Unio*, and near the top is a bed of sand with seams of lignite. This sand and lignite thickens eastward, while the plastic clays die out, till in the Soissonnais the group is represented by beds of lignite and black clays with associated marls and sands (30 to 50 feet). These contain *Cyrena cuneiformis*, *Melania inquinata*, and other Woolwich species. The highest beds are found at Sinceny on the Oise. They contain the same freshwater shells and consist of sands and clays with rolled flint pebbles.

Yprésian.—In France the London Clay is only found near Calais and Orchies; evidently it thinned out southward and does not appear to be represented elsewhere unless by the lower part of the sands of the Soissonnais, which are not more than 160 feet thick. These are divisible into three portions:—

Sables de Cuise with *Cyrena Gravesi* and freshwater shells.

Sables de Pierrefonds, *Turritella edita* and *Nummulites planulatus*.

Sables d'Aizy with *Rostellaria Geoffroyi*.

Lutétian.—In the Paris basin this stage consists of the beds generally known as the Calcaire Grossier. It is the most fossiliferous formation in the Paris basin, and the middle portion yields the light-yellow calcareous freestone which is the chief building stone of Paris. The group is divisible into three sub-stages as follows:—

	Feet.
3. Upper, thin-bedded fissile limestones with white and green marls and some beds of siliceous and dolomitic limestone, <i>Cardium obliquum</i> , <i>Cerithium denticulatum</i> , <i>Potamides lapidum</i> , <i>Lucina saxorum</i>	30 to 79
2. Soft thick-bedded limestones, some beds largely composed of <i>Miliola</i> and <i>Orbitolites</i> : <i>Cardium granulosum</i> , <i>Chama calcarata</i> , <i>Fusus bulbiformis</i> , <i>Turritella imbricataria</i>	25 to 40
1. Glauconitic limestones and sands with a layer of pebbles at the base, <i>Cerithium giganteum</i> , <i>Cardium porulosum</i> , <i>Ostrea flabellula</i> , <i>Nummulites levigatus</i>	25 to 70
	80 to 145

For these figures I am indebted to Messrs. G. F. Harris and H. W. Burrows and the Council of the Geologists' Association.

The Calcaire Grossier is succeeded by a set of sands known as the Sables Moyens or Sables de Beauchamp, which are about 30 feet thick. They form the zone of *Num. variolarius* and *N. Heberti*, and are also found at Anvers on the Oise, whence Mr. Dollfus has called them *Anversian*.¹⁶ Near Paris they are surmounted by a freshwater limestone, the Calcaire de Ducey, the fauna of which is different from that of the higher limestones.

Bartonian.—The argillaceous facies of this stage does not appear to exist in the Paris basin, where it is represented by sands alternating with freshwater limestones in the following succession, and having a total thickness of from 100 to 120 feet :—

4. Calcaire de Noisy with *Limnæa longiscata*.
3. Sables de Marines with *Corbula pisum*, *Natica ambulacrum*, and *Voluta athleta*.
2. Calcaire de St. Ouen with *Limnæa longiscata*.
1. Sables de Mortefontaine with *Avicula*, *Potamides tricarinatus*, and *Pot. concavus* (= *pleurotomoides*).

3. Southern Europe

After the general uplift which took place at the close of Cretaceous time (see p. 524) the south of Europe seems to have remained for a time above sea-level, but it gradually sank again and was covered by a sea which occupied the whole of the Mediterranean region. The mountain ranges of the Pyrenees, the Alps, and the Apennines were not yet in existence, and the Eocene or Nummulitic Sea extended from the north of Spain and south of France through the Alpine region to Bavaria and the Carpathian Mountains, and through Italy to the Balkan States, Greece, and Asia Minor. It also occupied parts of Northern Africa.

The northern parts of this sea were shallow, and the deposits are mainly arenaceous; the central parts were deep, and the prevalent deposits are limestones crowded with species of *Nummulites*.

Thus in Bavaria and near Vienna the Eocene consists of—

3. The Vienna Sandstone (upper part), which in Hungary contains *Num. striatus* and at Häring in the Tyrol includes a thick seam of coal.
2. Vienna Sandstone (middle part) and Kressenberg Beds of Bavaria, sands and marls with a bed of limestone, *Num. complanatus*, and *N. perforatus*.
1. Burberg Beds; greensands with small Nummulites, *Orbitoides* and *Operculina*. Probably of London Clay age.

Nothing comparable with the lowest Eocene deposits of England and France has yet been found in Central Europe, large parts of which must have been land, for a special feature in the Vienna Sandstone Series is the occurrence of beds of coarse conglomerate

and of large isolated blocks of granite and gneiss which appear to have come from Bohemia.

In Provence the Eocene is represented only by freshwater and terrestrial deposits, but south of it the Nummulitic Sea passed westward through the north of Spain and into Aquitaine. The Provençal deposits may be tabulated as follows, and are specially interesting from the nummulian remains which occur in them:—

Bartonian.—Freshwater clays, sands, and conglomerates.

Lutétian.—Limestones and marls with *Planorbis pseudo-ammonia*, *Limnæa aquensis*, and *Bulinus Hopei*, with bones of *Lophiodon Pachynolophus*, *Paloplotherium*, and *Hyracotherium*.

Yprésian.—Sands and mottled clays (freshwater).

Sparnacian.—Limestone with *Physa Draparnaudi* and *Limnæa obliqua*.

Thanetian.—Limestone with *Physa prisca* and *Melania*.

Montian.—Limestones with *Physa montensis*.

In the Southern Alps, Vicentin and Venetian districts, there is a more varied and complete series, and the succession according to von Hauer, but slightly modified by more recent researches, is as follows:

Ba.	{ Fine-grained sandstone or "macigno."
	{ Limestone with <i>Cerithium diaboli</i> .
	{ Volcanic tuffs of Ronca.
Lu.	{ Limestones with <i>Num. complanatus</i> and <i>N. perforatus</i> .
	{ Limestones with <i>Alveolina</i> , and fish beds of Bolca.
	{ Limestones with <i>Num. ataicus</i> and <i>Lithothamnium</i> .
	{ Limestones with flints, Brachiopods, and Nummulites.
Li.	{ Cosina Beds with <i>Melania</i> and <i>Chara</i> and leaves of <i>Dryandra</i> and <i>Banksia</i> .
	{ <i>Miliolina</i> limestone, with <i>Cerithium</i> and <i>Anomia</i> .

The letters to the brackets stand for *Liburnian*, *Lutétian*, and *Bartonian*, the Liburnian being apparently conformable to the underlying Cretaceous strata, and consequently representing nearly the whole of the Lower Eocene.

In the Northern Apennines, according to Professor Sacco,¹⁷ the Eocene Series attains a thickness of 5500 feet. At the base is a group which he classes as *Suessonian* (about 300 feet), succeeded by a great thickness of sandy and marly beds with marine fossils (*Lutétian*), surmounted by sandstones, shales, and shaly limestones with few fossils (about 5000 feet). At the top are 300 feet of grey marls with many fossils, including *Num. striatus* and *Orbitoides radians* (*Bartonian*).

II. THE OLIGOCENE SERIES

A. NOMENCLATURE AND DIVISIONS

The name *Oligocene* was proposed for this series by Professor Beyrich in 1854, who showed that it contained an important

fauna, differing considerably from that of the typical Eocene strata of England, France, and Belgium, and that it attained a considerable development in Northern Germany. The older classification arranged these beds partly in the Eocene and partly in the Miocene System, but this rendered it necessary to draw a line of separation between the two so-called systems in every area of deposition, and in the midst of a perfectly continuous series. The difficulty of making this separation, and the close connection of the faunas of the groups which were formerly called "Upper Eocene" and "Lower Miocene" respectively, has induced geologists to accept Beyrich's proposal to unite these groups under the name of Oligocene.

The following table shows the divisions which have been made in the Oligocene Series of England, Belgium, and France :—

England.	Belgium.	France.	Strata in Paris Basin.*
Hamstead Beds.	Rupelian.	Stampian.	Calcaire d'Etampes. Sands of Ormoy and Morigny, etc.
Bembridge Beds.	Upper Tongrian.	Sannoisian.	Calcaire de Brie. Marls and Clays. Upper Gypsum.
Headon Beds.	Lower Tongrian.	Ludian.	Lower Gypsum Beds. Marine Marls of Ludes.

B. LIFE OF THE PERIOD

The Oligocene flora does not differ in any great degree from that of Upper Eocene time ; species of *Sequoia* are still abundant ; palms are common ; leaves of cinnamons, laurels, figs, camphor-trees, acacias, chestnuts, and other trees occur.

The invertebrate fauna is not large and is a direct development from the Eocene fauna, the genera being all survivors from the Eocene. Echinoderms were not abundant in our northern seas, but were common in the Mediterranean area, especially forms of the genera *Echinolampas*, *Echinocyamus*, and *Celopleurus*.

Of Vertebrates the Mammalia deserve special attention. A large number of new genera make their appearance in the gypsum beds of Paris, which correspond to our Headon Beds and form the Lower Oligocene of English and German geologists. Prominent

among these are *Palæotherium* and *Anoplotherium*, the former allied both to tapirs and rhinoceroses, the latter an ungulate of comprehensive type, combining characters now found in the tapir, pig, and horse. There were several species of *Anoplotherium*, the largest being about the size of a donkey and having a long, thick, and strong tail which may have assisted him in swimming. *Anchitherium*, regarded as an ancestor of the horse, was no larger than a sheep, and had three hoofs on each foot. *Hypotamius* (see p. 529) was a common hog-like animal, and *Chæropotamus* is supposed to have been a river hog. *Dichodon*, *Xiphodon*, and *Cænotherium* were hornless forms of antelopes, and *Hyænodon* one of the early car-

Fig. 190.—RESTORATION OF PALÆOTHERIUM MAGNUM.

nivores resembling the marsupial wolf of Tasmania. In Southern France the jaw of a lemur (*Adapis*) has been found.

In higher Oligocene deposits corresponding to our Bembridge and Hampstead Beds other genera have been discovered, such as *Anthracotherium*, an ungulate remarkable for its strong canine teeth, and presenting several species which vary from the size of a hog to that of a hippopotamus. This beast and species of *Hypotamius* are very abundant in the higher Oligocene. Other genera now appearing are *Dacrytherium*, *Dremotherium*, *Elotherium* (*Entelodon*), all ruminants; the small carnivore *Plesictis*, and toward the close of the period the genus *Protapirus* with Rhinoceroses. Proboscidea are represented by *Palæomastodon* and other genera; and the Sirenia by *Halitherium*.

The following are some of the fossils which are characteristic of the British Oligocene Beds, and many of them also occur in France and Belgium. Species restricted to or most abundant in one of

the stages are given under its heading, but the following are more or less common in all three groups :—

Lamellibranchia. *Corbula pisum.*

Gastropoda. *Potamides elegans*, *Tomichia Duchasteli*, *Bayania fasciata*, *Melania acuta*, *Melanopsis carinata*, *Natica labellata*, *Neritina concava*, *Viviparus lentus*, *V. angulosus*, *Planorbis obtusus*, *P. platystoma*.

Reptilia. *Trionyx incrassatus* (a freshwater tortoise).

Fossils of the Heaton Beds and Lower Tongrian

Actinozoa. *Solenastrea cellulosa*, *Goniopora* (= *Litharea*) *brockenhursti*, *Madrepora anglica*.

Lamellibranchia. In the marine beds are : *Cardita deltoidea*, *Corbula cuspidata*, *Dosinia* (= *Cytherea*) *incrassata*, *Pecten bellicostatus*, *Ostrea velata*, *O. prora*, *Trinacria* (= *Trigono-coelia*) *deltoidea*. In the freshwater beds are : *Corbicula obovata*, *C. cycladiformis*, *Erodona* (= *Potamomya*) *plana*, *E. gregaria*, *Unio Solandri*.

Gastropoda. In the marine beds are : *Ancilla buccinoides*, *Cancellaria elongata*, *C. muricata*, *C. evulsa*, *Neritina aperta*, *N. concava*, *Pisania labiata*, *Voluta spinosa*, *V. geminata*, *V. decora*. In the freshwater beds : *Potamides concavus*, *P. ventricosus*, *P. vagus* (= *pseudocinctus*), *Limnæa longiscata*, *Melanopsis fusiformis*, *Stenothyra parvula*, *Planorbis euomphalus*, *P. lens*, *Helix oclusus*.

Mammalia. *Dacrytherium ovinum*, *Dichodon cervinus*, *Hyænodon minor*, *Palæotherium crassum*.

Fossils of the Osborne and Cambridge Beds

Plantæ. *Chara Lyelli*, *C. medicaginula*, *Flabellaria lemanonis*, *Cinnamomum* sp.

Lamellibranchia. *Corbicula semistriata*, *C. pulchra*, *C. obtusa*, *Ostrea vectensis*, *Arca Websteri*.

Gastropoda. *Glandina costellata*, *Amphidromus ellipticus*, *Cyclotus cinctus*, *Helix d'Urbani*, *H. pseudo-globosa*, *Viviparus lentus*, *Planorbis discus*, *Melania acuta*, *M. muricata*, *Potomacilis turritissima*, *Potamides mutabilis*.

Mammalia. *Anoplotherium commune*, *Chæropotamus gypсорum*, *Palæotherium magnum*, *P. medium*, *Xiphodon gracile*.

Fossils of the Hamstead and Rupelian Stage

Plantæ. *Chara tuberculata*, *Andromeda reticulata*, *Arthrotaxis* sp.

Lamellibranchia. *Corbula subpisum*, *C. vectensis*, *Dosinia* (*Sinodia*) *Lyelli*, *Ostrea callifera*, *O. cyathula*, *Pectunculus obovatus*, *Lucina Thierense*, *Leda Deshayesiana*.

Gastropoda. *Potamides plicatus*, *P. elegans*, *Tomichia Duchasteli*, *Bayania fasciata*, *Stenothyra* (= *Nematura*) *pupa*, *Voluta Rathieri*, *Tritonium flandricum*.

Mammalia. *Hyopotamus bovinus*, *Anthracootherium minus*.

Fig. 191.—GROUP OF OLIGOCENE FOSSILS.

- a. *Chara medicaginnula*.
- b. *Cyrena pulchra*.
- c. *Glandina costellata*.
- d. *Viviparus angulosus*.
- e. *Amphidromus ellipticus*.
- f. *Helix d'Urbani*.

- g. *Tomichia Duchasteli*.
- h. *Potamides elegans*.
- i. *Limnaea longiscata*.
- k. *Planorbis euomphalus*.
- l. *Dosinia incrassata*.
- m. *Voluta Rathieri*.

C. THE ENGLISH SERIES

Headdon Beds.—This group is divisible into three portions, Lower, Middle, and Upper, the Middle portion containing marine

and brackish-water shells, while the lower and upper are of fresh-water origin. These beds underlie all the northern part of the Isle of Wight, but except at the western end their outcrop is very narrow. They are well exposed in the cliffs which extend from Headon Hill to Cliff End, and also in Whitecliff Bay at the east end of the island (see map, Fig. 172). In Hampshire they underlie a large part of the New Forest, and the Lower Headon is exposed on the coast in Hordwell Cliff. Recently they have also been found in Dorset (Isle of Purbeck).¹⁸

The section at Headon Hill may be regarded as the typical one, although the total thickness is less there than elsewhere, being only 146 feet. The succession at this place is as follows:—¹⁹

		Feet.
Upper Headon, 46 feet	Variegated clays with <i>Erodona</i> (<i>Potamomya</i>) <i>gregaria</i>	21
	Limestone with <i>Limnæa longiscata</i> and <i>Planorbis euomphalus</i>	8
	Blue clays with the same <i>Limnæa</i> and <i>Planorbis</i>	5
	Limestone with the same fossils and 2 feet of sand below	12
Middle Headon, 33 feet	Clays with <i>Potamides concavus</i> , <i>Cyrena obovata</i> , etc.	7
	Limestone with <i>Limnæa</i> and <i>Planorbis</i>	1
	Sandy clays with marine fossils	15
	Sand and clays with <i>Neritina</i> , <i>Cyrena</i> , and <i>Cerithium</i>	10
Lower Headon, 67 feet	Limestone with <i>Limnæa</i> and <i>Planorbis</i>	3
	Sands and clays with carbonaceous layers and lignite	20
	Clays and sands with two beds of limestone, <i>Viviparus angulosus</i> , <i>Nematula parvula</i> , <i>Limnæa</i> , and <i>Planorbis</i>	25
	Sands and clays with <i>Erodona plana</i> , etc.	19

In Colwell Bay the Middle Headon contains many marine shells, such as *Ostrea velata*, *Dosinia* (*Sinodia*) *incrassata*, *Corbula cuspidata*, *Nucula headonensis*. In Whitecliff Bay the marine beds have expanded to 126 feet, and contain many of the Brocklehurst shells mentioned below, while the Lower Headon freshwater beds are reduced to 28 feet, a fact which suggests that part of these lower beds may be replaced by marine deposits.

The marine beds are found also at Brockenhurst and Lyndhurst in the New Forest, where they yield a rich fauna; 150 species of shells and corals have been found there, about half of which range up from the Barton Beds, but the fauna as a whole closely resembles that of the Tongrian in Belgium and Germany. Some of the commonest species are *Rimella rimosa*, *Cancellaria muricata*, *Pisania labiata*, *Pleurotomaria transversaria*, *Voluta decora*, *V. geminata*, *Cardita deltoidea*, *Dosinia incrassata*, *Corbula cuspidata*, with *Solenastrea cellulosa* and many other corals.

At Hordwell only the Lower Headon is exposed, and the beds are freshwater with a thickness of 83 feet.²⁰ Many reptilian and mammalian remains have been found at this locality.

Bembridge Group.—The lower beds of this group were separated by Professor Forbes in 1853, under the name of the St. Helens Beds, afterwards changed to “Osborne Beds.” In the *Memoirs of the Geological Survey* they are described as a separate group, but as the fossils they contain are not distinctive, and are all of freshwater species, they are certainly not entitled to rank as a stage. Professor Judd and Mr. H. Keeping group them with the overlying Bembridge Beds under the name of Lower Bembridge marls,²¹ and if this is adopted the Bembridge Group will consist of three members, as below:—

	Hamstead and Headon.	Whitecliff.
3. Upper marls	75	106
2. Bembridge Limestone	15	25
1. Lower marls or Osborne Beds	74	80
	<hr/> 164	<hr/> 211

The Lower or Osborne Marls at Headon Hill and Colwell Bay consist of white, blue, and red marls with calcareous concretions which contain *Limnæa longiscata*, *Planorbis discus*, *Viviparus lentus*, and other freshwater shells. At Whitecliff Bay they consist of dark-green clays and sands, but are much concealed by landslips, and the best sections occur along the north-eastern coast from Osborne to Nettlestone Point; here, however, they assume a very different facies, the lower 20 feet consisting of marls, with bands of hard yellowish sandy ragstone and shell limestone full of *Viviparus lentus* and *Melania excavata*, the upper 50 feet consisting of green and yellow sands alternating with marls and clays, containing *Melania excavata*, *Planorbis obtusus*, *Limnæa longiscata*, and *Cyrenæ*.

The Bembridge Limestone is a cream-coloured stone with interstratified marls; sometimes it is compact, sometimes quite tufaceous and concretionary; it is quarried at Headon Hill, at Sconce near Cliff End, and at Binstead near Ryde, and it is also exposed at Bembridge Point and in Whitecliff Bay. Its contents are terrestrial and freshwater, many species of *Helix*, *Amphidromus*, *Achatina*, *Glandina*, *Cyclotus*, *Clausilia*, *Limnæa*, *Planorbis*, and *Viviparus* occurring, with oviform bodies which are supposed to be the eggs of the large *Amphidromus*; stems and seeds of *Chara* are common, and mammalian remains are found in the Binstead quarries.

The Upper Bembridge Marls extend from the river Yar to Bembridge and Foreland Point, and occupy some space round Osborne, Ryde, and St. Helens. At Hamstead they consist entirely of freshwater beds, chiefly blue and green clays containing *Viviparus lentus*, *Melania acuta*, *Potamoclis turritissima*, *Melanopsis carinata*, *Cyrena semistriata*, and *C. pulchra*.

In Whitecliff Bay there is a marine bed near the base of these marls containing *Ostrea vectensis*, *Dosinia incrassata*, *Nucula similis*, and *Mytilus affinis*. About 50 feet up is a grey sandy limestone (4 feet thick) containing *Amphidromus* and *Glandina*, and the highest beds contain *Potamachis turritissima* in abundance.

The recent discovery of the Bembridge Limestone and Osborne Marls on Creechbarrow Hill in Dorset is important as showing that the Oligocene Series extended some distance westward, and that the Bembridge lake must have been a fairly large one.

The **Hamstead Beds** cover a large area extending from Yarmouth and Hamstead through Parkhurst Forest and across the Medina River to Brading Harbour. Throughout this tract they maintain a thickness of over 200 feet, and their base is everywhere marked by a band of carbonaceous clay. At Hamstead the succession is given by Mr. Reid as follows:—

	Feet.
<i>Marine Beds</i> with <i>Corbula vectensis</i> , <i>C. pisum</i> , <i>Ostrea callifera</i> , <i>Voluta Rathieri</i> , <i>Potamides plicatus</i> , <i>P. elegans</i>	31
<i>Leaf and Seed Beds</i> .—Red and green clays with carbonaceous layers containing leaves of palms and water-lilies and seeds	153
<i>White Band</i> .—Green clay with white shelly marls	6
<i>Nematura Beds</i> .—Green and black clays with <i>Stenothyra</i> (= <i>Nematura</i>) <i>pupa</i> , <i>Assiminea conica</i> , <i>Sphærium Bristovi</i> , <i>Hydrobia</i> (<i>Tomichia</i>) <i>Duchasteli</i>	64
<i>Black Band</i> .—Black clay with <i>Viviparus lenta</i> and <i>Unio</i>	2
	256

The "white band" is only traceable as far as Parkhurst Forest, but east of the Medina it appears to be represented by a bed of fine sand which, commencing near Newport, thickens eastward till it is about 40 feet and forms a marked feature on the surface.

D. CONTINENTAL REPRESENTATIVES

As in the case of the Eocene Series, the Oligocene deposits which are found in Belgium and Northern France can be correlated without much difficulty with those of our own country, but those of France include some beds which appear to be higher and newer than any which occur in England or Belgium. Again, in the central part of France there are lacustrine deposits of great thickness containing many fossils of great interest and associated with volcanic phenomena.

1. *Belgium*

The Oligocene occupies a large area in Belgium, and though the beds differ considerably in lithological character from those of the

Hampshire basin, the general succession corresponds very closely with that of our country. Belgian geologists have divided them into two stages: (1) the *Tongrian*, from Tongres near Limbourg, and (2) the *Rupelian*, from the river Rupel south of Antwerp, on which is situate the town of Boom.

Tongrian.—There is in most parts of Belgium a break between the Tongrian and the Eocene Series, the Oligocene having a layer of quartz-pebbles at the base which rests indifferently on various members of the lower series.²² It is divisible into two parts, a Lower and an Upper Tongrian. The Lower Tongrian is of small thickness, from 20 to 60 feet only, and consists of fine sands and sandy clays with *Ostrea ventilabrum* (= *O. prona*, Wood), *Astarte Omaliusi*, *Cardium porolosum*, *Dosinia incrassata*, *Pecten bellicostatus*, *Voluta decora*, *Clavella longæva*, *Cancellaria evulsa*,—a marine fauna which closely resembles that of Brocklehurst (Middle Headon).

The Upper Tongrian is an estuarine or fluvio-marine group, equivalent to the Bembridge Beds, and comprises three members, as below, but the total thickness is only 20 to 30 feet.

3. Sands of Vieux Jones with *Potamides plicatus* and *P. elegans*.
2. Green clays of Hénis with *Dosinia incrassata* and *Mya angustata*.
1. Sands of Bouterem with *Cyrena semistriata*, *Cerithium Lamarcki*, *Melania muricata*, *Bithinia helicella*, and *B. plicata*.

Rupelian.—This is a purely marine formation, and appears to be the equivalent of our Hamstead Beds. It commences with the sands of Berg, characterised by the abundance of *Pectunculus obovatus*, with *Voluta Rathieri*, *Cominella Gossardi*, *Tritonium flandricum*, and locally it includes a band of clay with *Nucula compta*.

The Upper Rupelian consists of a thick mass of sandy clay, the Argile de Boom, which contains many fossils, some of the more important being *Voluta Rathieri*, *Fusus elongatus*, *Triton flandricum*, *Corbula pisum*, and *Leda deshayesiana*; it has also yielded many remains of vertebrates, including two Sirenians (*Halitherium*), several birds, turtles, and a number of fish, chiefly Elasmobranch (*Lamna*, *Odontaspis*, *Oxyrhina*, *Carcharodon*).

2. Germany

Since the name *Oligocene* is based upon the deposits of this age found in the north of Germany they really form the type of the series, but although they occupy a large area in that country they are to a great extent concealed beneath Miocene and newer deposits. Here and there, however, the Oligocene Beds are

exposed at the surface, as at Latdorf near Bernberg, Egelu near Magdeburg, at Neu Brandenburg, and other places. They are the oldest Tertiary deposits in Germany, and the lowest beds are the sandy clays of Latdorf and Egelu, which contain *Ostrea ventilabrum* and the other fossils of the Lower Tongrian of Belgium, but the equivalents of the Upper Tongrian are not yet known at those places.

On the Prussian coast, near Königsburg, are other deposits of Tongrian age, the lowest being sands with *O. ventilabrum* and a bed containing pieces of amber, which is the resin of *Pinus succinifera* and other conifers. This amber encloses an immense number of insects and arachnids (about 2000 species), with leaves of *Pinus*, *Sequoia*, and other coniferæ—*Quercus*, *Acer*, *Castanea*, *Magnolia*, *Cinnamomum*, Palms, and other trees. The overlying beds are sands with layers of lignite.

Above the Tongrian is the Septarian Clay or Rupelian, which contains the same fossils as that of Belgium, and was clearly formed in a continuation of the same sea. It reaches a thickness of nearly 500 feet, but passes eastward into the Stettin sands.

To the south-west around Mayence on the Rhine is a small basin of Oligocene deposits which must have been formed in a gulf of the Northern Sea. The lower beds are similar to those of Germany and Belgium, but the Septaria Clay passes up into marl and sand with *Cyrena semistriata* and *Potamides plicatus*, above which are other sandy beds with *P. plicatus*, *Mytilus Faujasi*, and other brackish-water fossils, with some land-shells (*Helix*, etc.).

3. Switzerland

The northern part of Switzerland was also occupied by a sea during Oligocene time which seems to have been connected both with the Southern Sea and with the Gulf of Mayence. The area occupied by Oligocene and Miocene deposits is that of the great lakes between the Alps and the Jura, from Geneva to the Chiem See in Bavaria, a distance of 300 miles. The deposits are like those of Mayence but are much thicker, the upper or Rupelian part alone having a thickness of nearly 1000 feet and presenting the following succession :—

	Feet.
Freshwater beds with <i>Helix Ramondi</i> and <i>Planorbis declivis</i> }	
Marls with <i>Cyrena semistriata</i> and <i>Ostrea cyathula</i> }	60
Sandstone with <i>Potamides plicatus</i> and plants }	
Septaria Clay (few fossils except Foraminifera)	600
Sand with <i>Ostrea longirostris</i> , <i>Pectunculus obovatus</i> , <i>Cyrena semistriata</i> , <i>Potamides trochlearis</i> , etc.	300

Southward toward the Alps these beds pass into a great mass of shales, sandstones, and conglomerates which are called *Molasse* by the Swiss geologists and *Flysch* by the Germans and Austrians. Of these sandy deposits about 5000 feet belong to the Oligocene, and the lower part of them is probably of Tongrian age, but they contain very few fossils.

"Nothing," says Jukes, "is more calculated to strike the geological traveller on his first visit to Switzerland than the vast deposit of the 'Molasse,' occupying the central region between the Alps and the Jura. This is the country of the great lakes, extending from that of Geneva to that of Constance. The hills by which these lakes are environed have all the rugged and broken character of mountains, and rise in peaks of various altitudes up to that of 6050 feet, which is the height of Rhigi Kuhn. These hills, which, if they were not overshadowed by the still loftier Alps, would themselves be celebrated mountains, are composed from top to bottom of beds of sand and gravel, occasionally compacted into sandstones and conglomerate."

4. The Paris Basin

Ludian.—French geologists are not agreed as to the precise line of division between the Eocene and Oligocene Series, the fact being that there is a gradual transition from one to the other,²³ but it is generally conceded that the Lower Gypsum beds of Montmartre may be correlated with the Headon Beds of Hampshire, and it is convenient to retain the name **Ludian** (from Ludes, near Rheims) as a designation for these beds. Near Paris they comprise three beds of gypsum, separated by beds of yellow marl which contain a few marine fossils, but in the eastern part of the basin the marls predominate and are more fossiliferous, containing *Pholadomya ludensis*, *Cardium granulosum*, *Psammobia neglecta*, *Potamides concavus*, etc. The total thickness varies from 60 to 120 feet.

Sannoisian.—This includes the highest bed of gypsum, which is 65 feet thick at Montmartre and has yielded the bones of fifty different species of mammals, including *Palæotherium magnum*, *P. medium*, *Anoplotherium commune*, and *Xiphodon gracile*. This mass of gypsum may be regarded as contemporaneous with the Lower Bembridge or Osborne Beds and the Bembridge Limestone. Above are a set of marls known as the Supra-gypseous Beds; the lowest are white and blue marls with a few freshwater fossils, overlain by green marls containing *Cyrena semistriata*, *Dosinia incrassata*, *Psammobia plana*, *Potamides plicatus*, etc. Above there is another lacustrine deposit, the Calcaire de Brie, consisting

of white marls with beds of siliceous limestone which have been used for making millstones (*meulières*); total thickness about 100 feet.

Stampian.—This part of the series consists chiefly of sands which were formerly known as the “Sables de Fontainebleau,” but being more fossiliferous near Etampes to the south of Paris are now named after that village. The lowest bed is a marl containing marine fossils, *Ostrea cyathula*, *O. longirostris*, and *Corbula subpisum*. The overlying sands of Morigny and of Ormoy yield many fossils, including *Pectunculus obovatus*, *Lucina Thierensi*, *Voluta Rathieri*, *Tritonium flandricum*, and *Potamides plicatus*, a fauna which correlates them with the Rupelian of Belgium. At the top is a lacustrine limestone with *Helix Ramondi* and *Cyclostoma antiquum*, formerly known as the “Calcaire de la Beauce inferieur,” but now termed the Calcaire d’Etampes. The thickness of the Stampian Group near Paris is about 250 feet.

5. Central France

Extensive lakes were also formed in Central France during the Sannoisian epoch, and continued to exist through the Rupelian (or Stampian) and the greater part of Miocene time, leaving their records in the lacustrine deposits of the Auvergne, Cantal, and Velay. French geologists believe that there were three separate lakes, the largest and most northern occupying the valley plain of the Allier known as the Limagne d’Auvergne, the second being in Velay, and the third in the Cantal; but the latter is now for the most part buried below the volcanic mass of that district.²⁴

The deposits of the Limagne are the most complete and accessible; this plain has an average breadth of 20 miles, and its length from Nevers to Brionde is nearly 100 miles. It consists of nearly horizontal strata of sandstones, marls, and limestones, which often rise into low hills capped by fragments of ancient lava-streams. This tract is bounded both on the east and the west by lofty hills of granite and gneiss which rise to a height of 1600 feet above the plain and 3000 feet above the sea; and the western plateau supports a chain of extinct volcanoes from which in Miocene and Pliocene times lava-streams flowed into the valley below. The succession of the Oligocene portion of these deposits is as follows (see Fig. 194):—

		Feet.
St.	{ Limestones and marls with <i>Helix Ramondi</i>	200
	{ Marls with <i>Cypris faba</i> and <i>Limnæa pachygaster</i>	60
	{ Limestones with <i>Potamides Lamarcki</i>	160
Sa.	{ Sands and clays with marly partings and a limestone at the base, <i>Melania</i> , <i>Limnæa</i> , and <i>Cyrena semistriata</i>	200
	{ Sandy clays and coarse sands (arkoses)	150

From the Sannoisian of the Velay bones of *Palæotherium*, *Paloplotherium*, and *Entelodon* have been obtained.

6. Italy and Dalmatia

Parts of Southern Europe were covered by a more open sea than that of the northern region; it was, in fact, the Eocene Sea, shallowed and made less extensive by a slow movement of upheaval. Oligocene deposits reach a great thickness in Northern Italy, being found in Liguria, around Turin, in the Vicentin, and along the range of the Apennines, and they have been classified by Professor Sacco in the following manner:—²⁵

		Feet.
Stampian.	Grey sandy marls with few fossils	2000
Tongrian.	{ Sandy marls and sands with beds of conglomerate, <i>Nummulites Fichteli</i> , <i>N. intermedius</i> , <i>Natica crassa-</i> <i>tina</i> , <i>Cyrena semistriata</i> , and bones of <i>Anthrac-</i> <i>therium</i>	6000
Sestian.	Sandy marls with <i>Num. Fichteli</i> , <i>Num. vasculus</i> , etc. .	60

The lowest beds are conformable to the highest of the Eocene, and the Stampian marls are succeeded by the Miocene.

III. GEOGRAPHY AND SEDIMENTATION

We have seen (pp. 524 and 535) that the Cretaceous period closed with a general uplift of the whole European region, so that for a long time sedimentation was restricted to a few bays or gulfs, some dependent on the Southern Sea, and one reaching in from the far north to Belgium and the Paris basin.

There is some reason for thinking that the Atlantic Ocean began to assume its present form in Eocene time, or at any rate that its eastern trough between Europe and the medial sub-oceanic ridge, from which the Azores rise as mountain-summits, came into existence at this epoch; and that the depression of this trough was correlative with the uplift of the Western Franco-British region, which was accompanied by such wonderful volcanic eruptions.

After these early changes, however, a slow subsidence ensued, and the seas gradually spread their waters over larger spaces till about the middle of the Eocene period, or in Lutétian time, these seas had acquired their greatest extension. There was still land over the greater part of France, Germany, Poland, Russia, and Scandinavia, but there was a large southern sea covering the Mediterranean area, together with the most northern parts of Africa, and stretching eastward through Asia Minor and Syria far into Asia

The northern border of this sea passed through Switzerland, the south of Bavaria, Austria, and Southern Russia.

Westward this Nummulitic Sea passed by two channels into the western ocean, which occupied the Central Atlantic area; one of these channels lying through the south of Spain and Morocco, the other through the north of Spain, the Pyrenees, and Aquitaine, leaving Portugal and Central Spain to form a large island.

Moreover, the Atlantic Sea reached northward as far as the latitude of Cornwall, and a narrow channel of communication was established between it and the Northern Sea along the line of the English Channel. The proofs of this are found in a small outlier of Lutétian limestone lying directly on the Chalk near Orglandes in the Cotentin, in the fact of Lutétian fossils being sometimes washed up on the shore at St. Malo, and in a block of *Miliolina* limestone dredged up from the floor of the Channel 39 miles south of the Eddystone Rock.²⁶

This early English Channel, however, did not remain open very long, for its closure may be inferred from the great contrast between the faunas of the Bracklesham and the Barton Beds. The Bracklesham or Lutétian fauna has a semi-tropical aspect, and a large number of species are restricted to it, while the Bartonian fauna has a greater resemblance to that of the London Clay, the southern types having become extinct.

The movement which cut off the connection between the Western and Northern Seas seems to have been an uplift of the whole western area, for the Aquitanian channel was also closed and the eastern end of the Aquitanian basin converted into an area of marshes and lagoons. Farther east, however, in the Alpine region and in Northern Italy, the sea seems to have maintained its position.

With the commencement of Oligocene time a further change took place, consisting principally in the subsidence of Germany, Poland, and Central Russia, thus opening up communication between the Anglo-Gallic Sea and the Asiatic Sea above mentioned, so that many of the same species of shells occur both in Belgium and near Simbirsk in Russia, such as *Voluta suturalis*, *Ostrea flabella*, and *Astarte Bosqueti*. Various minor changes also took place, the sea penetrating into the Central European land by several channels and inlets, in which a variable series of marine, brackish, and freshwater deposits were laid down, while in France some alteration of the drainage system led to the formation of several large lakes.

It seems to have been about the beginning of Oligocene time that certain important physical changes took place in the British

region. During the Eocene period all the north-western part of our region formed a tract of high plateau-land on which a remarkable series of volcanic eruptions took place, as briefly described on pp. 544 *et seq.* The southern part of this western plateau is believed to have drained eastward or south-eastward across England, but after the cessation of volcanic activity crust-movements occurred, which resulted in the elevation of the Pennine range and the dome of the Lake District. Dr. Marr²⁷ has shown that the final uplifts of both of these areas took place in Tertiary times, and I have given reasons for assigning the date to late Eocene or early Oligocene time.²⁸

It is probable that these uplifts were correlative with the subsidences which formed the trough of the Hebridean Sea west of Scotland, and that of the Irish Channel between Ireland and Wales; these depressions then becoming broad valleys which drained southward, and thus formed new features in the geography of the British region. Moreover, the Pennine uplift was probably continued southward down the centre of England, forming a watershed which threw off streams to the east and the west, and thus initiating the valleys of the Severn and the Thames.

Recurring now to the area in which the varied succession of Eocene and Oligocene deposits took place, some remarks may be made on the source of the materials of which they consist. Of course, the sands and clays were carried down by the rivers which drained into the seas from the surrounding land, and the marine limestones are mainly of organic origin. Two kinds of sediment, however, are especially conspicuous; the one being clays of white, green, or variegated red and white tints, the other consisting of pale-coloured foraminiferal limestones.

The clays occur on many horizons, and are generally of a plastic nature; in England they are found in the Reading Beds, in the Bagshot sands, in the Bournemouth facies of the Bracklesham Beds, while in the Headon and Bembridge Beds green clays predominate, though white, red, and variegated clays are also of frequent occurrence. Similar clays occur at successive horizons in the deposits of the Paris basin.

The white clays have engaged the attention of several observers, the earliest writers attributing them to the detrition of granitic rocks and the decomposition of felspars. Mr. G. Maw,²⁹ however, in 1867 dissented from this view, regarding them as more probably derived from argillaceous chalks; Dr. A. Irving³⁰ also attributed the Bagshot pipeclays to the "decomposition of chalk and the leaching out of the iron by the action of peaty acids."

There are, however, strong objections to both these views; to

the first because the white clays occur at a considerable distance from the nearest areas of granite. It is true that there may have been granite masses not far south of the Isle of Wight, as Mr. O. Fisher has pointed out, and there may have been others between Normandy and Devonshire; still none of them are likely to have been large enough to provide so much pure argillaceous material. Again, with respect to the Chalk, the Eocene deposits rest nearly everywhere on Upper Chalk, which contains a very small percentage of clay. The Chalk-marl could have supplied a larger amount, but the contemporaneous outcrops must also have been some distance from the areas in which the Eocene Clays were being deposited, and a very large mass of Chalk-marl would be required to furnish the extensive beds of white clay that seem to have been formed. Much of the insoluble residue obtained from marly chalks is colloid silica, and the amount of alumina is generally small, the amount of argillaceous matter varying from 6 to 20 per cent, and much of this is glauconite, not clay.

Lastly, there seems no good reason for supposing that the white clays had a different source from the variegated clays of the Reading Beds or of the Oligocene Series. So far as is known, they only differ in colour, and this, as Dr. Irving points out, may be due entirely to the leaching action of peaty acids which would operate on clay derived from any source. He has also shown that the green colouring matter of certain Eocene sands and earths is due to decomposed vegetable matter, while we know that variegated white and red clays are common among lacustrine deposits of many ages all over the world.

It seems probable, therefore, that these fine Tertiary Clays are merely the fine muds brought down by rivers and streams from all parts of the country which surrounded the areas of deposition, and that their colour or want of colour is the result of the chemical actions to which they were exposed during their transportation and during the process of deposition, the red tints being due to the oxidation of iron or manganese, the green to the presence of decomposed vegetation, and the white to leaching out of all colouring matter.

With respect to the other prevalent kind of deposit mentioned on p. 569, that is more easily accounted for. The foraminiferal limestones are specially characteristic of the Mediterranean area of deposition, where they constitute masses of limestone many hundred feet in thickness. The ordinary "Nummulite limestone" has a pale buff or grey matrix, composed mainly of the debris of decayed and disintegrated Nummulites, in which are embedded more perfect tests of one or more species. The genera *Nummulites*,

Orbitoides (sub-genus *Orthopragmina*), and *Operculina* are the largest and most abundant forms; next to these *Alveolina* is perhaps the most important as a rock-builder, and in some districts the *Miliolida* occur in great profusion, as in the Miliolite limestone of the Paris basin, of which rock the sub-genera *Triloculina* and *Quinqueloculina* are the chief components.

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CHAPTER XVI

NEOGENE SYSTEM

MIOCENE AND PLIOCENE SERIES

THE Newer Tertiary strata, *i.e.* those which are newer than the Oligocene Series, have so much in common, both as regards their mode of occurrence and the species of fossils which they contain, that they can hardly be considered to form more than one system, and even when so grouped together it is only in the south and south-east of Europe that they constitute a series of deposits comparable in thickness and extent to those of older systems.

As explained on p. 526, the name Neogene will be adopted for this system, and it will be regarded as including the three groups or series which were termed Miocene, Pliocene, and Pleistocene by Lyell. It is true that many geologists, both in this country and on the Continent, exclude the Pleistocene from the Neogene System and place it in what they call a Quaternary or Post-Tertiary System, but the only essential difference between the Neogene and the Quaternary is that the remains of man have hitherto only been found in the latter. It would, however, be rash to say that man did not exist during the later part of Pliocene time, and thus the distinction on which a Quaternary System is based must be regarded as an assumption. No hard-and-fast line can be drawn between deposits of Pliocene and Pleistocene age, and from a purely geological point of view it is more logical and correct to say that Tertiary time merges into the Recent or Historic period than to imagine that Tertiary time ended when man first appeared.

When the Miocene, Pliocene, and Pleistocene Groups were established by Lyell the percentage of living species of Mollusca in each fauna was taken as a guide and as a criterion of age, but subsequent researches have shown that the percentages originally adopted by Lyell cannot be sustained, and that if the principle is to be retained the proportional numbers must be altered, and further, that much latitude be allowed in certain cases. It may be considered, however, that the Miocene molluscan fauna has only from ten to forty

living species, the Pliocene from forty to ninety, and the Pleistocene from ninety to a fauna without species that are more than locally extinct, and finally to one that does not differ from that of the surrounding country or neighbouring sea.

Some geologists, however, prefer to take the mammalian faunas as a guide instead of the molluscan, and to take note of the extinction of genera rather than of the introduction of new species. Agreement on this question has not yet been reached, and there are differences of opinion as to the respective limits of the three series.

I. THE MIOCENE SERIES

A. NOMENCLATURE AND DIVISIONS

Although Continental geologists have differed on the question of including the stage known as *Aquitanian* in the Oligocene or in the Miocene, the latter view is now the prevalent opinion in France. It is adopted not only by de Lapparent in the last edition of his *Traité de Géologie* (1906), but its propriety has been placed almost beyond doubt by Mr. G. F. Dollfus in his recent revision of the typical Aquitanian fauna.¹ His examination shows that the number of species of marine Mollusca common to the Stampian and the Aquitanian of the Bordeaux district is only thirty-four, or about 10 per cent of the total; while the number of those common to the Aquitanian and the overlying Burdigalian is 164 or 55 per cent, so that the affinity of the Aquitanian fauna with that of the Miocene is five times as great as with the Oligocene. Even when compared with the still later (*Helvetian*) fauna of Touraine a proportion of 38 per cent is found to be common to the two.

There is also much difference of opinion with respect to the upper limit of the series, some placing both Sarmatian and Pontian in the Miocene Series, but Fuchs and others regard the Pontian Beds, which include what is known as the Pikermi fauna, as belonging to the Pliocene. In the present state of our knowledge it seems best to draw the line of division between these two groups, and to consider the Sarmatian as the highest member of the Miocene. Thus defined, the Miocene Series is divisible into five stages: the Aquitanian and Burdigalian having their typical development in the Bordeaux district, the Helvetian in Switzerland and in Touraine, the Tortonian at Tortona in Italy, the Sarmatian in Austria and Southern Russia.

The following table shows the succession of deposits which are attributed to the Miocene in each of these districts. The only representative of the series in the British Isles are the Bovey Beds in Devonshire, which were correctly referred to the Aquitanian

by Heer in 1867, but were supposed to be Eocene by Starkie Gardner in 1879.² Mr. C. Reid,³ however, has recently shown that the flora is identical with that of the lignites of Wetteran near Bonn on the Rhine.

B. LIFE OF THE PERIOD

Flora.—The Miocene flora does not differ very greatly from that of the Oligocene period, and indicates a climate of sub-tropical warmth, but that of the highest stage furnishes evidence of a certain diminution of temperature and probably of an increase of the winter's cold. It was during this period that palms ceased to be abundant in Central Europe.

The earliest Miocene flora is that of the Aquitanian, the Bovey Beds and their equivalents in Northern Germany. This flora includes an abundance of the Conifers—*Sequoia*, *Taxodium*, and *Glyptostrobus*, associated with palms of the genera *Phœnicites*, *Flabellaria*, and *Sabal*, many deciduous trees, such as *Quercus*, *Laurus*, *Vitis*, *Magnolia*, and *Liquidambar*, and several ferns, *Osmunda lignitum*, *Lastrea styriaca*, and *Lygodium Gaudini*. A fauna of a similar character occurs in the Swiss Burdigalian.

Another well-known flora is that of the Ceninghen Beds of Switzerland, from which no fewer than 475 species of plants were obtained by Professor Heer. In this assemblage palms are rare, and the commonest trees are maples, planes, poplars, and elms, with species of Cinnamon, Camphor, Vine (*Vitis teutonica*), Fig-tree, Cypress (*Taxodium*) and *Glyptostrobus*, with a few *Proteaceæ*.

Looking to the Miocene flora as a whole, Professor Heer remarked that "increased prominence is given to the Japanese types by the abundance of camphor-trees and *Glyptostrobi*; to the Atlantic element by the laurels; to the American types by the numerous evergreen-oaks, maples, poplars, planes, liquidambars, *Robinia*, *Sequoia*, *Taxodia*, and ternate-leaved pines; and to the types of Asia Minor by the *Planera* and a species of poplar (*Populus mutabilis*). The greatest number and the most important of the types of the Swiss Miocene flora belong, therefore, to a belt lying between the isothermal lines of 59° and 77° Fahr., and in this zone America is now the region which is most correspondent to the natural character of the Swiss Miocene land."

Fauna.—Among invertebrate animals the Echinoderms are perhaps the most noteworthy, and they are conspicuous members of the marine fauna in the French, Italian, and Austrian regions; the principal genera are *Clypeaster*, *Echinodiscus* (*Amphiope*), *Scutella*, *Echinolampas*, *Spatangus*, and *Arbacia*.

Nearly all the marine Mollusca belong to living genera, but form

TABULAR CORRELATION OF MIOCENE DEPOSITS

Stages.	Aquitaine.	Orléanais and Touraine.	Auvergne.	Switzerland.	Italy.	Austria.
Sarmatian	Wanting.	Sands with <i>Cardita striatissima</i> .	Wanting.	Wanting.	Sands, marls and Radiolarian Beds.	Sands and marls.
Tortonian {	Absent.	Helix marls. Molasse of Anjou.	Sands and clays with <i>Dinotherium</i> .	Limestones of Ceninghen.	Livorno limestone. Tortona marls.	Leithakalk.
Helvetian {	Upper molasse of Armagnac. Faluns of Salles.	Faluns of Touraine.	Basalts.	Marine molasse. The Nagelfluh.	Sandy molasse. Superga Beds.	Badentegel and Grund Beds.
Burdigalian {	Faluns of Saucats. Faluns of Leognan. Molasse of Leognan.	Sands of the Sologne. Sands of the Orléanais.	Sands and marls of Gergovia.	Grey molasse of Lausanne.	Langhe marls and sands.	The Schier. Gaudernsdorf Beds.
Aquitanian {	Grey limestone of the Agenais. Sands of Larioz. Faluns of Bazas	Limestone of the Orléanais. Marls of the Gâtinais.	Sandstone with plants. (Gap.)	Red molasse and freshwater limestone.	Schio Beds.	Horn and Molt Beds.

an assemblage which resembles that now found in the Carribean Sea more than that of the existing Lusitanian and Mediterranean provinces, and the same is the case with the Echinoderm fauna.

Among Lamellibranchs the prevalent genera were *Arca*, *Lucina*, *Tivela* (*Grateloupia*), *Tellina*, *Cardita*, and *Ostrea*. Of Gastropods

Fig. 192.—GROUP OF MIOCENE FOSSILS (natural size).

a. *Cassidea saburon*.

c. *Arca barbata*.

b. *Arca glandiformis*.

d. *Ostrea crassissima* (young).

e. *Clypeaster*

altecostatus.

there is a most i variety, the chief genera being *Conus*, *Fusus*, *Melongena*, ^{fau}*Uvula*, *Murex*, *Cassidaria*, *Pleurotoma*, *Oliva*, *Ancilla*, *Turritella*, *Potamides*, *Cerithium*. The only known representatives of the tetrabranchiate Cephalopoda are the genera *Nautilus* and *Aturia*; the dibranchiate order is represented by *Spirulirostra*.

It is, however, the vertebrates, and especially the Mammalia, which form the most characteristic and distinctive features of the Miocene fauna. When this fauna is contrasted with that of the Oligocene the principal changes are seen to be as follows: (1) the appearance of Proboscidea in Europe, genera *Dinotherium* and *Mastodon*; (2) the replacement of the Palæotheres and Anthracotheres by Tapirs and by true Rhinoceroses, both of the hornless (*Aceratherium*) and horned type (*Rhinoceros*); (3) the occurrence of *Anchitherium*, an ancestor of the horse; (4) the appearance of large cats (*Machærodus*) comparable to modern panthers and tigers; (5) the appearance of monkeys and apes; (6) appearance of horned deer, *Dicroceras* (= *Procervulus*) (allied to the Muntjac of India); (7) the disappearance of marsupials from Europe.

The assemblage of animals was thus very different from that of Oligocene times, *Aceratherium*, *Anthracotherium*, and *Amphicyon* being almost the only mammals that survived from the one period to the other. The pig tribe were represented by *Palæochærus*, which first appears in the highest Oligocene of the Allier, and by *Hyootherium*, a closely allied genus. *Listriodon* was another two-toed and pig-like beast. The carnivores include *Machærodus* (the sabre-toothed tiger), *Amphicyon* (a progenitor of the dogs and bears), *Hyænarcos* (a bear-like animal), with otters (*Lutra*), cats, and foxes. Beavers made their dams across the streams; a gigantic ant-eater (*Macrotherium*) tore up the ant-hills with his great claws; lastly, true apes made their appearance, several forms being known (*Pliopithecus*, *Dryopithecus*), these being anthropoid apes of large size.

The *Dinotherium* was remarkable for having two large tusks in the lower jaw which curve downwards and are supposed to have been used by the animal to moor himself to the banks of the lakes in which he lived while he fed upon the herbage. The *Mastodon* had long tusks in both jaws, and was more like an elephant in build, and probably also in habits.

C. THE MIOCENE IN ENGLAND

The *Bovey Beds* rest on Devonian and Carboniferous rocks, and occupy a basin-shaped depression between Dartmoor and the Haldon Hills, extending for about 9 miles from Pullabrook near Bovey Tracey to Kingskerswell near Newton Abbot. They consist in the lower part of thick beds of lignite and of brown clay, and in the upper part of alternating beds of sand and clay, with some layers of lignite. Their total thickness has been estimated at about 600 feet, a boring at Heathfield having been carried to a depth of 526 feet without reaching their base, while west of the place it is believed that higher beds come in; where the base is exposed at

Staple Hill there is a bed of pebbles and stones overlain by some thickness of sand dipping steeply toward the east (see Fig. 193).⁴

The lignites are described by Pengelly and Heer as consisting mainly of Sequoia wood and the compressed fronds of *Osmunda lignitum*. The leaves and seeds of the following plants are also common: *Nyssa*, a tree now living in the southern United States; *Quercus Lyelli* (an evergreen oak), *Cinnamomum* (two species), *Vitis teutonica* and several other species, *Palmacites* (the prickly cactus), and the water plants *Stratiotes Websteri* and *Potamogeton tenuispina*.

D. CONTINENTAL MIOCENE

1. France (Aquitaine)

Aquitanian.—The typical Aquitanian is found in the near Bordeaux,⁵ and the typical marine fauna of this stage occurs in the "faluns" or calcareous shelly sands of Bazas and Lariez, some of the commoner species being *Ostrea aginensis*, *Arca cardiiformis*, *Turritella Desmaresti*, *Protoma Basteroti*, *Neritina Ferussaci*, *Cerithium calculosum*, *C. fallax*, *Melongena Lainei*, *M. cornuta*, *Oliva clavula*, and *Nassa aquitanica*.

These beds are overlain by a freshwater limestone containing *Helix Morognesi* and *Planorbis Mantelli*; this "calcaire gris de l'Agenais" must not be confounded with the "calcaire blanc de l'Agenais," which forms the top of the Oligocene, and is characterised by *Helix Ramondi* and *Cyclostoma antiquum* (see p. 566).

Burdigalian.—The typical Burdigalian fauna is that of Leognan; some of the characteristic species are *Turritella terebralis*, *Protoma cathedralis*, *Tudicula rusticula*, *Pecten burdigalensis*, *Clypeaster marginatus*, and *Scutella subrotunda*. On the Sancats horizon *Agaronia* (= *Oliva*) *Basteroti* and *Dorsanum baccatum* are common shells.

Helvetian.—The faluns of Salles furnish another fauna in which figure *Voluta* (*Scaphella*) *Lamberti*, *Cassidea saburon*, *Pecten solarium*, *P. scabrellus*, *Cardita Jouanneti*, and *Panopæa Menardi*. Eastward these marine sands pass into a freshwater formation, the molasse of Armagnac, consisting of marls of various colours (yellow, green, and red), limestones and calcareous sandstones, the whole said to be 1000 feet thick. The lower beds yield bones of *Mastodon angustidens*, *Rhinoceros sansannensis*, and *Amphicyon major*; the upper beds those of *Mastodon tapiroides*, *Dinotherium giganteum*, and *Anchitherium aurelianense*.

2. Orléanais and Touraine

Aquitanian.—The deposits of this age in the north of France are entirely of freshwater origin, and comprise the larger part of

the formation which was formerly known as the Calcaire de la Beauce, from which the Calcaire d'Etampes has been separated (see p. 566). The Miocene part is now called the Calcaire de l'Orléanais, and in the Gâtinais district the two are divided by a band of greenish marl or clay, which is taken at the base of the Aquitanian. The thickness of these marls and limestones is about 100 feet, and with the Calcaire d'Etampes they overstep all the older beds both southwards and westwards so as to lie directly on the Cretaceous and Jurassic rocks. Their characteristic fossils are *Helix aurelianense*, *H. Morognesi*, *Limnæa pachygaster*, and *Planorbis solidus*, with remains of *Anchitherium aurelianense*.

Burdigalian.—The Orléanais Limestone is overlain by an extensive deposit of granitic sands, the Sables de l'Orléanais and the Sables de la Sologne, which are divided by a band of white and green marls with *Melania Escheri*. The sands have been derived from the contemporaneous erosion of the Central Plateau, and outlying patches of them extend westward to Blois and Poitiers and northward to Rouen and Havre. The thickness of the group is about 90 feet, and the lower sands contain remains of *Mastodon angustidens* and two other species, *Dinotherium Cuvieri*, *Rhinoceros aurelianense*, and *Amphicyon*.

Helvetian.—This does not occur within the limits of the Paris basin, but consists of a number of separate tracts and patches of shelly calcareous sand around Blois, Tours, and Angers, with others to the north-west near Rennes and Dinan in Brittany. These beds were termed *Falunian* by d'Orbigny from the peasant's name of *falun* for this kind of material, which resembles that known as *crag* in the east of England. The beds are marine, and mark an invasion of the western ocean. The most typical fauna is found near Pontlevoz and Savigné, and some of the commoner fossils are *Arca turonica*, *Ostrea crassissima*, *Pecten scabrellus*, *Lucina Dujardini*, *Trochus miocenicus*, *Potamides pictus*, *Conus (Conospira) Dujardini*, and *Nassa limatula*.

Tortonian.—In this western area (Maine and Anjou) there is a still newer set of deposits, distinguished by the abundance of Bryozoa with fragments of *Lithothamnium* (a calcareous alga), many Echinoderms of the genera *Amphiope*, *Scutella*, and *Echinolampas*, and the teeth of large sharks, *Carcharodon* and *Oxyrhina*.

3. Auvergne and Velay

Aquitanian.—Since the limestones with *Helix Ramondi* are now referred to the Oligocene, there is little to represent the Aquitanian in this part of France, and M. Dollfus believes that there is a gap (lacuna) or want of continuity in the series of lacustrine deposits.⁶

Fig. 193.—SECTION ACROSS THE BOVEY BASIN NEAR HEATHFIELD. Distance about 3½ miles.

a. Sands and gravel.

P. Palaeozoic rocks.

S.S. = Sea-level

c. Clays and sands.
b. Brown clays and lignite beds.

Fig. 194.—SECTION THROUGH THE COUNTRY NEAR PERRIER (Auvergne). By Munier-Chalmas and Michel Lévy.

a¹ Ancient alluvium.

a² Basaltic lavas.

p¹ Upper Pliocene.

p² Middle Pliocene.

ms. Miocene marls and sands.

m. Oligocene limestones and marls.

In many places the *Helix* limestone is directly overlain by marls with *Melania Escheri*, but on Gergovia hill near Mardogne there is a sandstone containing the remains of plants which seem to be an Aquitanian assemblage.

Burdigalian.—This is represented by marls and sands containing plant remains and a few shells such as *Melania Escheri*, *Melanopsis callosa*, *Cyrena* and *Unio*. Above these beds are basaltic lava flows and thick beds of volcanic ash.⁷ The sands of Givreul near Moulins, which contain bones of *Dinotherium*, also belong to this stage.

Helvetian.—No beds of this age have yet been recognised.

Tortonian.—The deposits referable to this stage are also scanty, but beds of coarse sand and clay near Aurillac have yielded remains of *Dinotherium giganteum*, *Hipparion gracile*, and *Machairodus cultridens*. In the Cantal also are extensive deposits of shaly clays and lignites associated with volcanic ash and basaltic lavas which contain the same Mammalian fauna and plant-remains analogous to those of Ceninghen mentioned hereafter.⁸

4. Switzerland

Aquitanian.—The only deposits in the northern plain which can be attributed to this stage (as now restricted) are the gypsiferous beds near Lausanne which overlie those containing *Helix Ramondi*, and in which are found other species of *Helix* with *Planorbis*, *Neritina*, *Potamides*, and *Cyrena*, and bones of *Anthracotherium*. Part of the "red molasse" is probably of the same age.

Burdigalian.—Near Lausanne the above are succeeded by the "grey molasse," a set of sandstones and marls no less than 1000 feet thick, mainly of freshwater origin and containing the remains of a flora in which palms (*Sabal*, *Phœnicites*, and *Flabellaria*) are associated with figs, laurels, acacias, maples, cinnamon, and some *Proteaceæ*.

Helvetian.—East of Lausanne the highest freshwater beds appear to pass into estuarine deposits with *Ostrea crassissima* and *Potamides lignitarum*, and these are covered by the shelly marine molasse which is more fully developed in Freiburg and Berne. In St. Gall and Appenzell there are beds of an intermediate character consisting of red marly sands with bands of conglomerate, the sands containing *Cardita Jouanneti*, *Panopæa Menardi*, *Pectunculus pilosus*, *Conus ventricosus*, etc. To this stage also belong a great part of the conglomerates of the Nagelfluh, which contain pebbles of various rocks not now occurring in the Swiss Alps.

Tortonian.—The Ceninghen Beds, consisting mainly of shaly limestones, occur on the northern border of the Lake of Constance, and have yielded an enormous number of plants, insects, fish, and

reptiles. Heer described nearly 500 species of plants, and the assemblage indicates a cooler climate than that of earlier Miocene time. It contains a mixture of generic forms which are now characteristic of widely separated countries (see *ante*, p. 574). Among insects wood-eating beetles are particularly abundant. With these are remains of fish and freshwater tortoises, a huge salamander (*Andrias Scheuchzeri*), which was taken for a human skeleton when first discovered; also bones of *Dinotherium giganteum*, *Mastodon tapiroides*, *Palæomeryx eminens* (a ruminant), *Galecynus Eningensis* (a fox having affinities with the civet cat), hares, beavers, and many small carnivores.

5. Austria

The Miocene has a wide extension in Austria, and consists there mainly of marine deposits which occupy the Vienna basin and extend thence eastward to Moravia and the Carpathian Mountains. Their thickness varies in different places, but the average may be estimated at about 1500 feet.

Aquitanian.—The lowest beds are the sands and clays of Horn and Molt containing *Potamides plicatus*, *Pectunculus Fichteli*, and *Mytilus Haidingeri*, which seem to represent only the higher Aquitanian.

Burdigalian.—To this stage may be referred the sands of Gaudernsdorf containing *Turritella turris*, *T. cathedralis*, and other fossils of the Léognan fauna, also the molasse of Eggenburg consisting of sand and Bryozoan limestone. Of about the same age are the gypsiferous marls known as the "Schlier" containing *Pecten denudatus*, *Cryptodon angulatus*, *Solemya Doderleini*, and *Aturia Aturi*.

Helvetian.—The Grund Beds are sandy marls which contain a fauna like that of the faunas of Touraine, and the Baden Tegel are marly clays of about the same age but containing rather a different assemblage of shells, species of *Pleurotoma* being more abundant, with *Cardita Jouanneti*, *Ancilla glandiformis*, *Cassidea saburon*, *Pecten cristatus*, and *Corbula gibba*.

Tortonian.—This seems to be represented by the Leithakalk, a limestone consisting largely of *Lithothamnion* and *Foraminifera* (*Amphistegina* and *Triloculina*), but in some beds Bryozoa are very abundant and in others Corals with many bivalve shells (*Pecten latissimus*, etc.), large Echinoderms (*Clypeaster altcostatus*, *C. marginatus*), and teeth of sharks (*Carcharodon*, etc.).

Sarmatian.—This consists mainly of sand and soft sandstone, but includes some beds of sandy limestone and marl, the whole being about 800 feet thick, but reaching 1200 feet in Galicia.

Shells are exceedingly abundant, but the number of species is not large, and the fauna is that of an enclosed sea, with much cooler water than that of the older Mediterranean. The Cones, Olives, Cypræas, and Ancillas have all disappeared, and the commonest shells are species of *Cerithidæ*—*Potamides pictus*, *Cerithium rubiginosum*, *Potamides disjunctus*—with the bivalves *Tapes gregarius*, *Mastra podolica*, *Ervilia podolica*, and *Cardium obsoletum*. The flora is similar to that of Eeninghen, and the Mammalian remains include *Mastodon angustidens*, *Anchitherium aurelianense*, and *Listriodon splendens*.

6. Italy

The Miocene Series of Italy is thicker than that of Austria and must have been found in a deeper sea, the floor of which was probably a subsiding area, for the beds attain a thickness of about 6500 feet.

The *Aquitanian* is represented by the Schio Beds of the Vicentin district, which are marls from 700 to 1000 feet thick containing the Foraminifer *Lepidocyclus* with *Scutella subrotunda* and many kinds of fish. In Liguria its equivalent probably exists in the sandy marls at the base of the so-called *Laughian* Group.

Burdigalian.—The typical equivalent of this is found near Langhe in Liguria, where sandy marls with *Pecten (solarium and burdigalensis)* pass up into blue marls with *Aturia Aturi*, *Solemya Doderleini*, and many Pteropod shells; the whole having a thickness of 2000 feet (Mayer).

Helvetian.—This stage is described as having a thickness of over 3000 feet in Liguria and as divisible into three groups, a lower consisting of whitish marls full of Pteropoda (1300 feet), a middle of sandy molasse with Bryozoa and *Pecten ventilabrum* (650 feet), and an upper of nullipore beds with *Pecten* and Oysters (300 feet). The *Superga* Beds of Turin belong to the same stage, and contain the fauna of the *Touraine* faluns.⁹

Tortonian.—Succeeding the above are about 650 feet of blue marls with an abundant shell fauna, rich in species of *Pleurotoma* and *Conus* with *Voluta rarispina*, *Ancilla glandiformis*, *Apollon marginatus*, *Trochus patulus*, and corals of the genera *Turbinolia* and *Stephanophyllia*. The assemblage indicates a sea that was rather warmer than the Mediterranean of the present time.

Sarmatian.—In Liguria the Tortonian is overlain by about 60 feet of marls and sands containing a limited fauna like that of the Austrian beds, *Potamides pictus*, *Cerithium rubiginosum*, *Pecten cristatus*, etc. In other parts of Italy, on both sides of the Apennines, in Calabria and in Sicily, there are extensive beds of

siliceous earths (*tripoli*), composed largely of *Diatoms* and *Radiolaria*, with a fauna containing some Helvetian survivals, such as *Cardita Jouanneti* and *Pecten aduncus*, mixed with the characteristic Sarmatian species of *Tapes* and *Ervilia*.

7. Belgium and Germany

Our survey of the European Miocene would not be complete without a brief notice of the Belgian and German equivalents. These are of small thickness, and comprise only two stages, the Bolderian, which probably represents the Helvetian, and the Anversian, which corresponds with the Tortonian or Sarmatian.

The *Bolderian*, or sands of the Bolderberg, about 30 feet thick, and contain a fairly large fauna, including *Conus Dujardini*, *Murex Nysti*, *Ancilla obsoleta*, *Terebra Basteroti*, *Panopæa Menardi*, and *Venus multilamella*. They rest on the Rupelian Clay, and have at their base a pebble-bed containing blocks of septaria derived from that clay and often pierced with *Pholas*-borings.

The sands of Anvers (*Anversian*) are dark glauconitic sands about 20 feet thick, and contain layers almost entirely composed of the shells of *Pectunculus pilosus*; other common species are *Pirula condita*, *Turritella subangulata*, and *Corbula striata*.

A gulf of the Bolderian Sea seems to have extended into the north-west of Germany through Schleswig-Holstein, Mecklenburg, and Hanover, as far as the Teutoburg and Oldenburg. The deposits consist of sand at the base overlain by micaceous clay, and the commoner fossils are *Terebratula grandis*, *Arca diluvii*, *Pectunculus pilosus*, *Isocardia cor*, *Pecten Janus*, *P. decussatus*, *Conus Dujardini*, and *C. antediluvianus*.

E. HISTORY OF THE MIOCENE PERIOD

During the course of this period a succession of uplifts and terrestrial disturbances took place by which great changes were produced in the geography of Europe. The first change, *i.e.* that from Oligocene to Miocene conditions, seems to have been a general uplift, causing a general retreat of the seas, both northern and southern, and raising the greater part of Northern Europe into dry land. At the same time it is clear that the elevation of this land was not great, and that its lower levels in France, Switzerland, and Germany were occupied by large lakes. The deposit formed in these lakes preserves the remains of a flora which indicates a mild semi-tropical climate, inducing a rich vegetation which supported a large mammalian fauna.

These conditions seem to have continued through Burdigalian time, at any rate in Northern Europe, but in the southern region,

and more especially in the south-east, subsidence occurred which carried the sea northward through Provence into Dauphiné and Savoy, through parts of Switzerland, and through Austria and Hungary to the Carpathian mountains. The history of this epoch has not yet been very clearly deciphered, and there may have been too great a desire on the part of some continental geologists to find an equivalent of each stage in every region. In other words, it is not certain whether all the stages recognised in France are represented in Switzerland and Austria; and in some districts there are indications of a break at the base of the Helvetian stage.

Suess divided the Miocene Series of Central and Eastern Europe into two groups, which he called the first and the second "Mediterranean Stages," and he came to the conclusion that the main upheaval of the Alpine chain took place in the interval between them. Subsequent researches have tended to confirm this view, and it is generally believed that it was at the close of the Burdigalian or the beginning of Helvetian time that the greatest orogenetic movements took place. By these movements the rocks of the Alpine ranges were bent into sharp flexures and overfolds, and whole tracts of strata were thrust northward over and along planes of dislocation. These pressures ridged up the older rocks of Switzerland and Austria into mountains upon which rain and running water came into active operation, and some of the results are exhibited in the Nagelfluh conglomerates of Northern Switzerland (see p. 581).

According to Suess, while the Alps were being ridged up in the manner above mentioned, "in other places, as in parts of Tuscany, Austria, Western Hungary, and Styria, great in-sinkings were formed, and in these lie leaf-bearing lignitiferous beds which are immediately subsequent in age to the Schlier. It is about this time that the Alpine basin of Vienna was broken in, that the Alps were separated from the Carpathians, that the eastern downbreak of the Alps with the gulf of Gratz was formed, that the way was paved for the subsequent discharge of the Danube to the east, and that the Tuscan part of the inner Apennine depression was formed or at least indicated. It is probable that most of the inner Carpathian subsidences belong to this period." It seems more likely, however, that these subsidences were of subsequent date, and led to the extension of the Helvetian Sea over these areas.

At the same time in Northern Europe the effect of these crust-pressures showed itself along the old lines of Armorican and Hercynian folding, a new series of flexures was produced along these lines across the south of England and through the north-east of France, Belgium, and Germany. It was by these movements

that the London, Hampshire, and Paris basins were formed and separated from one another, and it is specially noticeable that the sharpest flexures are along the southern sides of the Hampshire and London basins. The well-known monocline of the Isles of Wight and Purbeck is one of these flexures, and that of the Hog's Back ridge west of Guildford is another. The general result was to elevate the whole of Northern Europe into high ground on which no large areas of deposition seem to have existed.

After these disturbances there seems to have been a partial subsidence; the Atlantic Sea of Helvetian time invaded the west of France, and occupied not only part of the Aquitanian area but also that which is now the valley of the Loire, forming a gulf which reached as far up as Blois. The sea also passed northward by Rennes to Gahard and Dinan, so that the central and western parts of Brittany were probably reduced to the condition of an island. The Southern Sea also spread northward through Provence and Dauphiné to the Jura, and thence round the northern side of the Alps to Austria, through parts of Bavaria to Bohemia and Poland, and eastward through Galicia and across the south of Russia. There must also have been some connection between the French or Swiss gulfs and the Belgian Sea, though by what route has not yet been definitely ascertained; it is certain, however, that such shells as *Conus Dujardini*, *C. antediluvianus*, and *Terebra Basteroti* must have come from the south.

The concluding phase of this period seems to have been produced by a general uplift of the southern region, which raised parts of the Mediterranean area into dry land and led to the formation of the shallow Sarmatian Sea, a large enclosed sea which extended from the Danubian basin through the Pontic area to the Caspian region, with a gulf that stretched southward into the Ægean area. The two main basins of the Mediterranean seem also to have been occupied by shallow seas which covered parts of Italy and Sicily and reached westward to the neighbourhood of Barcelona in Spain, where sands and marls with *Cerithium pictum* and *Macra podolica* are found, but the rest of Spain appears to have been part of the Continental area, and the westward opening of the Mediterranean into the Atlantic lay through Morocco.

II. THE PLIOCENE SERIES

A. SUBDIVISIONS AND NOMENCLATURE

In most parts of Europe the Pliocene deposits are of small thickness and of no great extent, and were mostly accumulated in

shallow seas not far removed from the existing coast-lines of the Continent. Of such deposits good examples exist in England and Belgium. The only areas where marine deposits of Pliocene age attain any great thickness are Holland, Italy, and the south-east of France, but there is also a large area in the south-east of Europe, where the Sarmatian Beds (see p. 573) are succeeded by another set of deposits formed in a similar inland sea. These *Pontian* Beds are only represented in Western Europe by a few isolated lacustrine and terrestrial accumulations which yield a similar mammalian fauna.

The great extent and thickness of the Italian Series (over 2000 feet), and the abundant marine fauna which it contains at successive horizons, have caused it to be regarded as the type of the Pliocene in the south of Europe. It has been divided into three stages named after Italian localities, and those names have been adopted in France. In the northern region, on the other hand, names have been given to small subdivisions which have no higher stratigraphical value than zones, and are only useful in the detailed correlation of the sequence found in one area with that of another. In a former edition of this book I grouped these zones into Lower, Middle, and Upper Stages, and as these correspond very closely with the major divisions of the Mediterranean Series, the same nomenclature will be employed in the present edition.

With regard to the deposits of the eastern inland sea, there is no reason to suppose that they are older than the lowest marine Pliocene Beds of Italy, *i.e.* those to which the name Messinian was given by Professor Sacco; they may therefore be included in the Lower Pliocene group or stage, and the divisions which have been made in different countries may be correlated as follows:—

TABULAR CORRELATION OF THE PLIOCENE SERIES

Stages.	England.	Belgium and Holland.	Provence.	Italy.	Austria and Greece.
Upper {	Cromer Beds and Upper Crag.	? Absent.	Sands with <i>Elephas meridionalis</i> }	Sicilian.	Sicilian.
Middle {	Red Crag, Walton Crag.	Amstelian. Scaldisian.	Sands with Mastodon.	Astian.	?
Lower {	Coralline Crag. Lenham Beds. Absent.	Casterlian. Diestian. Absent.	Congeria Beds. Luberon Beds.	Plaisancian. Messinian.*	Paludina Beds. Pontian.

B. LIFE OF THE PERIOD

Plants.—The flora of the Pliocene is transitional between the luxuriant, more or less, evergreen vegetation of the Miocene period and the temperate flora of modern Europe. In Southern Europe the plant-assemblage was similar to that of Oeningen, but without palms or cactuses. Later plant-beds give evidence of a gradual refrigeration of the climate, and toward the close of the period, if we may judge from the plants of the Cromer Beds, the climate of Northern Europe cannot have been very different from that of the present day.

Fauna.—Of the Invertebrata the majority of the species are either identical with, or merely varieties of, species now living, and the proportion of extinct species gradually diminishes from a percentage of 36 to 40 in the lowest beds to one of 10 or 11 in the highest beds. Very few of the fossils belong to extinct genera, but *Congeria* may be mentioned as a genus of Dreisseniidæ which is not now living.

Among the Vertebrata, however, many in the Lower Pliocene belong to extinct genera, and the majority of the species even in the higher stages are extinct. With the advent of the Pontian epoch and its southern land-connections with Africa and Asia, a new mammalian fauna invaded the plains of Europe. This included large herds of antelopes and gazelles, varying in size and form, and for the most part allied to those of Africa. With these was an animal of intermediate form between the giraffe and antelopes (*Helladotherium*), allied to the short-necked giraffe or okapi recently discovered in Africa. Herds of small wild asses (*Hipparion*), intermediate in structure between *Anchitherium* and the horse, also appeared in great numbers. Numerous carnivores followed and preyed on the herbivorous animals, large cats and panthers, including *Machærodus* (a tiger), *Hyæna*, *Ictitherium* (allied to the civet cats), *Hyænictis* (combining characters of cats and hyænas), and several species of true cats (*Felis*). The higher Pliocene is distinguished by the appearance of elephants (*Elephas*), oxen (*Bovidæ*), true horses (*Equus*), bears (*Ursus*), and wolves (*Canis lupus*), and by the abundance of deer (*Cervidæ*).

In France and Italy the Pliocene deposits are characterised by *Mastodon* (*Tetralophodon*) *arvernensis*, *Rhinoceros* (*Diceros*) *megarhinus*, *R. (Cælodonta)* *etruscus*, *Elephas meridionalis*, *Hippopotamus major*, *Capreolus cusanus*, *Elaphus perrieri*, *Axis pardinensis*, with *Machairodus cultridens*, *Hyæna striata*, bears, and wolves.

The following are some of the marine fossils which are characteristic of the several divisions of the Pliocene Series, but as the

faunas of the Northern and Southern Seas were somewhat different, those restricted to the southern region are indicated by an asterisk :—

Fig. 195.—GROUP OF CORALLINE CRAG FOSSILS.

- a. *Echinus* Woodwardi.
 b. *Tennechinus* Woodi.
 c. *Terebratulina* grandis.
 d. *Astarte* Omalii.

- e. *Cardita* senilis.
 f. *Voluta* Lamberti.
 g. *Brissus* unicolor (= *Scilla*).
 h. *Fascicularia* aurantium.

Fossils of the Lower Pliocene

Echinodermata. *Echinus* Woodwardi, *Tennechinus* Woodi, *Brissus* unicolor.

Bryozoa. *Cupularia* canariensis, *C. porosa*, *Theonoe* (= *Fascicularia*) aurantia, *Alveolaria* semiovata, *Salicornaria* crassa.

- Brachiopoda.* Terebratula spondylioides (=T. grandis).
Lamellibranchia. Arca (Anadara) diluvii, Cardium papillosum, Tellina Benedeni, Cardita senilis, Astarte mutabilis, A. Omalii, Cyprina rustica, Isocardia cor, Congeria simplex,* U. subglobosa,* Pecten benedictus,* Ostrea cochlear,* O. princeps.
Gastropoda. Conus (Conorbis) Dujardini, Pleurotoma (Clathurella) consobrina, Terebra acuminata, Tritonium (Ranularia) heptagonum, Voluta (Scaphella) Lamberti, Pyruia reticulata, Fusus lamellosus, Nassa (Amycla) semi-striata,* Turritella subangulata.*

Fig. 196.—GROUP OF RED CRAG FOSSILS.

a. Neptunea contraria.	d. Cardium Parkinsoni.
b. Cassidaria bicatenata.	e. Pectunculus glycymeris.
c. Buccinopsis Dalei.	f. Carcharodon megalodon.

Fossils of the Middle Pliocene

- Actinozoa.* Balanophyllia calyculus.
Echinoderma. Echinoecyamus pusillus.
Lamellibranchia. Astarte obliquata, Dosinia exoleta (lentiformis), Cardium Parkinsoni, C. angustatum, Lucina borealis, Mactra constricta, M. (Spisula) ovalis, Tellina (Macoma) obliqua, Pecten jacobæus.*
Gastropoda. Nassa (Uzita) reticosa, Neptunea contraria, N. antiqua, N. despecta, Purpura lapillus, P. tetragona, Columbella (Anachis) sulcata, Natica hemiclausa, Scala grœnlandica, Tritonofusus gracilis.
Fish teeth. Carcharodon megalodon.

Besides the above the following are equally common in the Coralline and Red Crags—*Astarte Burtini*, *Mactra (Spisula) arcuata*, *Pecten opercularis*, *Pectunculus glycymeris*, *Venus casina*, *Cassidaria bicaenata*, *Buccinopsis Dalei*, *Trochus Adansoni*, *Turritella incrassata*, *Natica millepunctata*, *Nassa labiosa*.

Fig. 197.—FOSSILS OF THE RED CRAO.

a. Balanophyllia calyculus.	e. Mactra constricta.
b. Echinocyamus pusillus.	f. Columbella sulcata.
c. Astarte obliquata.	g. Natica hemiclausula.
d. Cardium angustatum.	h. Purpura tetragona.
i. Nassa reticosa.	

Fossils of the Upper Pliocene

Lamellibranchia. *Astarte borealis*, *A. compressa*, *Cardium edule*, *Cyprina islandica*, *Yoldia oblongoides*, *Nucula Cobboldiae*, *Mya truncata*, *Mactra (Spisula) subtruncata*, *Tellina (Macoma) calcaria*, *T. (Macoma) obliqua*, *T. (Macoma) prætenuis*, *Scrobicularia plana*.

Gastropoda. *Potamides tricinctus*, *Buccinum groenlandicum*, *Melampus pyramidalis*, *Littorina littorea*, *Natica catena*, *Purpura lapillus*, *Turritella communis*.

Most of these species occur also in the Chillesford Beds, with the addition of *Cardium grænlandicum* and *Yoldia lanceolata*, and most of them are found in the Weybourn Crag, which latter is specially characterised by the incoming of *Tellina* (*Macoma*) *balthica* (= *T. solidula*).

The Norwich Crag has also yielded the following mammalia :—*Elephas antiquus*, *Cervus carnutorum*, *Equus stenorhis*, *Trogontherium Cuvieri* (an extinct beaver), *Gazella anglica*, *Arvicola intermedius*.

C. BRITISH PLIOCENE DEPOSITS

The English Pliocene was formerly divided into two groups, a lower and an upper, it being supposed that there was a decided break between the Coralline Crag and the Red Crag, both faunally and physically; but recent researches have shown that most of the common fossils of the Coralline Crag occur also in the more southern part of the Red Crag, while it also appears that the higher crags to the north of Aldeburgh are quite as distinct from the Red Crag as that is from the Coralline. Hence the series seems to fall naturally into three groups or stages, which may be tabulated as below :—

Upper	{	Cromer Beds (= Forest Bed)	}	about 200 feet.
		Weybourn Crag . . .		
		Chillesford Beds . . .		
		Norwich Crag . . .		
Middle	{	Butley Crag	}	combined up to 70 feet.
		Red Crag {		
		Newbourn Crag		
		Walton Crag		
Lower	{	Coralline Crag . . .	}	about 70 feet.
		Lenham Beds . . .		thickness unknown.

The Lenham Beds are only found in Kent, and the Coralline Crag only in Suffolk, though in Cornwall there are sands which are probably of about the same age as the latter. The newer crags occupy parts of Essex, Suffolk, and Norfolk, lying unconformably either on the London Clay or the Chalk. The only other traces of the Pliocene period in England are a deposit of sand in Dorset containing bones of *Elephas meridionalis*,¹⁰ and a cave in Derbyshire which has yielded bones of that and other Pliocene animals.¹¹ In Scotland shells of Upper Pliocene species occur in the Glacial deposits of the eastern coast, and indicate a northern extension of these Crags.

Lenham Beds.—The oldest Pliocene deposits in England are certain patches of ferruginous sand which occur at intervals along the Chalk downs of Kent from the heights above Folkestone to those above Maidstone, most of them being about 600 feet above

the sea. They were first described by Professor Prestwich in 1857, and more fully explored by Mr. C. Reid in 1886.¹² The Lenham Beds are mere remnants of a deposit which must originally have had a wide extension, not only in England but eastward through Belgium. These remnants have been preserved because they have subsided into deep pipes and hollows caused by the solution of the underlying Chalk. The hollows are lined with brown clay full of unworn flints, and these clay walls enclose a set of sandy deposits, yellow and red sands, reddish fossiliferous sandy ironstone, and greenish sand with scattered flint pebbles.

From these beds, and chiefly from the ironstone, Mr. C. Reid obtained sixty-seven species of Mollusca, and all but fifteen have been found in the Coralline Crag, so that there cannot be much difference in their relative age in spite of the great difference in relative level. There are, however, some species which do not occur in the Coralline Crag, but are found in the older Pliocene or later Miocene Beds of Europe; these are *Arca diluvii*, *Cardium papillosum*, *Terebra acuminata*, *Pleurotoma consobrina*, *P. Jouanneti*, the first two shells being very abundant. On the whole, therefore, the Lenham Crag is probably older than the Coralline, and Mr. F. W. Harmer thinks that it was considerably older.¹³

Some patches of similar sand occur farther on the Surrey downs, but no recognisable fossils have yet been found in them, and it is consequently uncertain whether they are of the same age.

The nodule bed at the base of the Suffolk Crags contains many rounded lumps of tough brownish sandstone which are known as boxstones, and have evidently been derived from an older deposit. Many of these contain fossils, and some of them are species which occur in the Coralline Crag, but two are only known from the older Pliocene of the continent; these are *Conus Dujardini* and *Voluta auris-leporis*.

Coralline Crag.—This crag is only found over a small area in Suffolk between Aldeburgh and Boyton, and in three other small isolated patches at Sutton, Ramsholt, and Tattingstone (see map, Fig. 198). It rests on an eroded surface of the London Clay, and its basement-bed (as seen at Sutton) contains a remarkable assemblage of materials derived from older deposits, and chiefly from the London Clay; the pebbles are chiefly phosphate nodules of a dark-brown colour, but with these are fragments of septaria, a few small pebbles of quartz and flint, and the boxstones which have been mentioned above; there are also Crustacea and fish teeth derived from the London Clay, reptilian vertebræ from the Oxford Clay, mammalian teeth of doubtful age, many Cetacean

Fig. 108.—MAP OF A PART OF THE PLOCENE AREA IN ESSEX AND SUFFOLK (by F. W. Harmer).

bones and teeth, and some sharks' teeth which are probably of Pliocene age, such as *Odontaspis hastalis* and *Carcharodon Rondeleti*. Above the nodule bed there are yellowish marly sands and fine quartz sands, with layers of comminuted shells, from 30 to 40 feet thick, and these form the lower portion of the Crag; above them at Sutton, Gedgrave, and Aldeburgh come about 36 feet of a soft porous yellowish-brown calcareous rock, consisting largely of comminuted shells and fragments of Polyzoa, which are often arranged in oblique laminae, while the bedding is of that irregular kind due to the action of rapid and changeable currents. This soft limestone has probably been formed by the infiltration of carbonate of lime from the overlying Red Crag. Fossils are abundant in both portions.

The Mollusca of the Coralline Crag (if they are not drifted) indicate a sea of some depth (40-60 fathoms), with warmer water than that of the existing North Sea. According to S. V. Wood's summary in 1874 the total number of species was 391, of which 142 were extinct, while 249 are identical with recent forms. Of these living species 205 occur in the Mediterranean, while only 174 occur in British seas, 50 being Mediterranean species which are not British, and 20 British species which are not Mediterranean. Wood has also pointed out "that the most abundant and therefore the most characteristic species of the Coralline Crag are southern species unknown to British seas, and that among the 154 which occur both in British and Mediterranean waters there are many which are really characteristic Mediterranean shells, and are only marked as British in consequence of some rare occurrence."

St. Erth Beds.—At St. Erth, near Hayle in Cornwall, and at an elevation of about 100 feet above the sea, there is an interesting deposit of sand and clay, the latter containing shells which prove it to be of Pliocene age. A pit near the vicarage exposed the following beds:—

	Feet.
Loamy clay full of angular stones	2 to 6
Fine gravel and coarse ferruginous sand	4 to 6
Clay, yellow above, blue beneath, and containing many fossils	6
Fine foundry sand, base not exposed	?10

The number of Mollusca which have been found in the clay is between eighty and ninety, and the greater part of them are such as occur in the lower part of the Red Crag, but many species of a southern character are present, such as *Fusus corneus*, *Nassa recticostata*, *Nassa mutabilis*, *Cardium papillosum*, and *Cardita aculeata*, which do not occur in the eastern crags, while the Boreal and Arctic forms found so abundantly in the higher part of the Red Crag are absent at St. Erth.

Mr. C. Reid has pointed out that the proportion of extinct forms, so far as the fauna has been worked out, is 41 per cent, which exactly corresponds with the proportion in the Coralline Crag;¹⁴ and in view of this and of the preponderance of southern Mollusca, he concludes that the St. Erth Beds are of older Pliocene age. Mr. Robert Bell, Professor Kendall, and Mr. Harmer are, however, all opposed to this view, and consider that the St. Erth Beds correspond more nearly with the older part of the Red Crag. From the nature of the deposit, from its geographical position, and from the occurrence of beach deposits round St. Agnes Beacon up to 375 feet above the sea-level Mr. Reid infers that the fossiliferous clay was formed at a depth of 40 or 50 fathoms.

Red Crag.—Returning now to the eastern counties we come to the deposit which is generally known as the Red Crag, this name denoting the usual reddish-brown colour of the material, which differs considerably from that of the Coralline Crag. The latter (when not decalcified) is a light-yellow calcareous deposit consisting chiefly of organic debris with some fine sand, while the Red Crag is a ferruginous shelly sand, its unaltered portions consisting partly of quartz-sand and partly of shells (either perfect or broken), the whole stained by a variable proportion of peroxide of iron (from 5 to 16 per cent).

This formation covers a much larger area than the older (Coralline) crag, and is apparently continuous over a space of about 300 square miles in Suffolk, but is so often concealed by the sands and clays of the Glacial Series, that generally it is only on the slopes of the valleys which intersect the district that the crag actually comes to the surface. The best exposures occur in the cliff-sections of Walton-on-Naze, Felixstow, Bawdsey, and in the valleys of the rivers Orwell and Deben.

The Red Crag rests partly on the London Clay and partly on the Coralline Crag, wrapping round the isolated reefs of the latter, and filling up the hollows between them. At its base there is generally a bed of phosphatic nodules with "boxstones" and other derived pebbles, together with rolled bones and teeth of mammalia and of sharks. The manner in which the Red Crag is banked against the Coralline Crag is illustrated in the section, Fig. 199. In the pits near Sutton there is evidence of two shore-levels, an upper and a lower cliff-line. The upper cliff is about 12 feet high, the lower shore-line is about 9 feet below the upper, and these two shore-lines are traceable all round the small mass of Coralline Crag which evidently formed a reef in the Red Crag Sea.

From the researches of Mr. S. V. Wood¹⁵ and Mr. F. W. Harmer¹⁶ it appears that the crag in the southern part of this area is

decidedly older than that in the northern part. The beds at Walton-on-Naze yield a fauna that Mr. Harmer considers to be closely allied to that of the Coralline Crag, for it includes many southern species and very few of northern origin, while at Butley in the northern part of the area northern species are abundant and southern forms are comparatively rare. Thus it seems as if these Red Crags were deposited while the sea was gradually retreating northwards, the slowly receding waters leaving a succession of beach and shallow-water deposits behind them. This shelly crag is seldom more than 20 feet deep at any one place, and its bedding is generally oblique, so that it may be described as consisting of a number of shelly sand-banks, each composed of highly inclined laminae, one bank often being sharply truncated by another.

Mr. Harmer has recently divided the Red Crag into three parts on the basis of the changing proportion of northern and southern species, and these divisions may be termed the Walton Crag, the Newbourn Crag, and the Butley Crag. The relations of these crags is best expressed by the following table of percentages, in the compilation of which Mr. Harmer has taken into account only the more abundant and characteristic species.

	Extinct Species.	Southern Species.	Northern Species.	Species of Northern and Southern Range.
Butley Crag . .	13	13	23	47
Newbourn Crag .	32	16	11	36
Walton Crag . .	36	20	5	35
Coralline Crag .	38	26	1	31

The Walton Crag is characterised by the abundance of *Neptunea contraria*, *Columbella sulcata*, *Nassa labiosa*, *N. elegans*, *Trochus Adansonii*, *Buccinopsis Dalei*, and *Dosinia exoleta*; the Newbourn Crag by abundance of *Cardium angustatum*, *Macra ovalis*, *M. constricta*, and *Tellina obliqua*; the Butley Crag by *Neptunea antiqua*, *Buccinum granlandicum*, *Cardium granlandicum*, *Nucula Cobboldia*, *Tellina obliqua*, and *T. prætenuis*.

Norwich Crag.—This group has a more extended range than either of the older crags, since it is found more or less continuously through Eastern Suffolk from Aldeburgh to Bungay and Beccles, and thence through Norfolk to Brundall and Norwich (on the river Yare), and to Coltishall and Burgh in the Bure Valley, a distance of about 40 miles. It is well exposed at several localities in the neighbourhood of Norwich, whence it takes its name; it is a variable group of sands, laminated clays, and pebbly gravels,

Fig. 190.—SECTION TO SHOW THE RELATIVE POSITIONS AND THICKNESSES OF THE EAST ANGLIAN CRAGS
(by F. W. Harmer in *Quart. Journ. Geol. Soc.* vol. lvi. p. 734). Distance about 45 miles.

Fig. 200.—SECTION THROUGH THE CRAG-PITS NEAR SUTTON (after Professor Prestwich). Distance about half a mile.
a. Coralline Crag. b. Red Crag. c. London Clay.

with occasional seams or patches of shells, and different local names were given to different portions of the group before it was ascertained that they all belonged to one division of the Crag.

Mr. F. W. Harmer remarks that "the Norwich Crag Beds are separated by a considerable interval [of time] from any part of the Red Crag. Their molluscan fauna has a much more recent character; they never exhibit the highly inclined bedding so characteristic of the Red Crag, and they attain a much greater thickness than the latter; they occupy an entirely different area, and appear to have originated under somewhat different conditions."¹⁷

The Norwich Crag appears to cut off the Coralline Crag abruptly near Aldeburgh (see Fig. 199), and it probably also truncates the Red Crag, for the latter has never been recognised north of that place, while the newer crag thickens northward very rapidly. In a boring at Leiston, only 2 miles from the border of the Coralline Crag, it was found to be 134 feet thick, at Southwold 147 feet, and at Lowestoft 180 feet were traversed without reaching its base.

Norwich Crag is not well exposed in any cliff-section, but a few feet of it are seen at the base of the cliffs near Southwold and Easton Bavent, where the succession is as follows:—

	Feet.
<i>Glacial Beds</i> —Bedded sands with flint pebbles . . .	up to 7
<i>Chillesford Beds</i> —Bedded sand and clay . . .	„ 12
<i>Norwich Crag</i> —Sand with three layers of shells . . .	„ 4

At Aldeby, on the north side of the river Waveney, a brickyard exposes a similar succession, and about sixty-six species of Mollusca have been obtained from the shelly sands. A special feature of this locality is that many of the bivalves occur with united valves in the position of life; they include *Mya arenaria*, *M. truncata*, *Yoldia oblongoides*, *Y. lanceolata*, *Lucina borealis*, *Macra ovalis*, *Scrobicularia plana*, *Tellina lata*, and *T. obliqua*.

Farther west along the same valley this crag is exposed in many pits near Norwich, Bramerton, and Brundall. The beds vary from 15 to 20 feet in thickness and consist mainly of sand with occasional seams of brown clay, and have generally a bed of rolled flints and pebbles at the base, in which mammalian bones and teeth have been found.

Chillesford Beds.—There has been much difference of opinion about these beds and their relation to the Norwich Crag. The geological surveyors (Messrs. W. Whitaker and C. Reid¹⁸) distinguish between Chillesford Crag and Chillesford Clay, regarding the former as part of the Norwich Crag and the latter as a separate and higher horizon. Mr. Harmer agrees with these

authors that what has been called Chillesford Crag or Aldeby Beds is in most localities indistinguishable from Norwich Crag, but he differs from them in regard to the sand below the clay at Chillesford, which he regards as belonging to the Chillesford Beds, believing it to be an exceptional bed without a parallel elsewhere.

The Chillesford Beds consist of finely laminated clay and sand, always micaceous, lying horizontally, and often in alternating layers of clay and sand. They are often from 18 to 20 feet thick; they rest indifferently on the Coralline, the Red, and the Norwich Crag, and have been traced from Walton-on-Naze to Mundesley in Norfolk, a distance of about 90 miles. Mr. Harmer has pointed out that when the exposures of these beds are plotted on a map they arrange themselves in the form of a sinuous band of gradually increasing width as it is traced northward, a form which suggests that they were formed in the estuarine portion of a large river flowing from south to north, and if this was so, the river was probably a continuation of the Rhine.¹⁹

Weybourn Crag.—This is only found in the north of Norfolk, and takes its name from Weybourn on the coast near Cromer, where it consists of from 1 to 12 feet of loam and sand with a band of blue clay in the lower part and a basement bed of unworn flints resting on the Chalk. Its characteristic shell is *Tellina balthica*, which is very abundant and is a northern species that does not occur in the older crags. Out of fifty-three species of Mollusca only five are extinct, and all the rest are such as now live in the North Sea, nine being regarded as Arctic forms, which is a larger proportion than occur in the Norwich Crag. The fauna, therefore, seems to indicate that the Weybourn Crag is newer than the Norwich Crag, and Mr. Harmer believes it to be newer than the Chillesford Beds.

Cromer Beds.—These beds are exposed at intervals along the Norfolk coast from Happisburgh to Weybourn. They have been described by many writers, and were carefully explored for the Geological Survey by Mr. C. Reid, who found the general succession in these cliffs to be as follows:—²⁰

							Feet.
Pleistocene	{	Glacial deposits					
		<i>Leda myalis</i> Bed					4 to 15
Pliocene	{	Upper freshwater bed					
		Forest bed (estuarine)					
		Lower freshwater bed					
		Weybourn Crag					1 to 12
						Cromer Forest Bed .	10 to 20

The Lower freshwater bed is a local and discontinuous deposit, its relation to the central estuarine portion resembling that of more recent "submerged forests" to the mud of modern estuaries. The

middle division consists of clay, sand, and gravel in irregular layers, and contains a mixture of marine and freshwater shells with many mammalian bones; it received its name of "Forest Bed" from the frequent occurrence of stumps, logs, and matted roots of trees, but these are not in the position of growth, as formerly supposed; they have all been drifted, though probably not from any great distance, and Mr. Reid concludes that they grew on the side of a steep river-bank which was continually being undermined and washed away by the current, "and settling generally in an upright position, as we should expect from the greater density of the roots and from the weight of the adhering soil, they have formed 'snags' in the river, such as are constantly met with in streams flowing through a forest-clad country."

The upper surface of this estuarine deposit is often weathered into a soil and penetrated by small roots (hence termed the Rootlet Bed), and is in some places covered by lacustrine deposits containing freshwater shells, with remains of Fish, Amphibia, and small Mammalia; this is the Upper freshwater bed.

The marine Mollusca, of which there are only nineteen species, all occur in the Weybourn Crag, and include some extinct species, as *Melampus pyramidalis*, *Tellina obliqua*, and *Nucula Cobboldie*.

With respect to the land and freshwater Mollusca these number sixty-two, of which thirty-three also occur in the Norwich, Chillesford, and Weybourn Crags. Of the others, which do not occur in older beds, some are extinct, e.g. *Viviparus gibbus*, *Limax modioliformis*, *Nematura runtoniana*, and *Pisidium astartoides*, and some no longer live in Britain, e.g. *Hydrobia marginata*, *H. Steini*, *Valvata fluvialilis*, and *Corbicula fluminalis*.

The mammalian remains are also numerous and important, and when the species are arranged in three groups, as below, it is seen that they prove the beds to have been formed just at the epoch of transition from Pliocene to Pleistocene time, a certain number being survivals from the Pliocene (either of Britain or France), and about an equal number being new-comers which range to Pleistocene or to modern times, while a few have not yet been found elsewhere.

(1) *Survivals from Pliocene*, 19

Elephas meridionalis.	Cervus poligniacus.
„ antiquus.	„ Etueriarum.
Rhinoceros etruscus.	„ elaphus (stag).
„ megarhinus.	„ verticornis (=C. belgrandi).
Hippopotamus major.	Machærodus latidens.
Equus stenonis.	Trogontherium Cuvieri.
„ caballus (horse).	Castor fiber (beaver).

Ursus arvernensis.
Canis lupus (wolf).
Cervus Sedgwicki.

Microtus (= *Arvicola*) *intermedius*.
Lutra vulgaris (otter).

(2) *New-comers ranging to Newer Beds, 19*

Bison bonasus (var. *priscus*).
Ovibos moschatus (musk ox).
Ursus spelæus (cave bear).
 „ *ferox* (grizzly bear).
Gulo luscus (glutton).
Canis vulpes (fox).
Mustela martes (marten).
Hyæna crocuta.
Sus scrofa (wild boar).
Myogale moschata (musk shrew).

Sorex vulgaris (shrew).
 „ *pygmæus* (pigmy shrew).
Talpa europæa (mole).
Mus sylvaticus (mouse).
Microtus arvalis (field vole).
 „ *gregalis*.
 „ *amphibius* (water vole).
Microtus glareolus (red vole).
Sciurus vulgaris? (squirrel).

D. CONTINENTAL PLIOCENE DEPOSITS

1. *The Pliocene in Belgium and Holland*

In these countries a succession of beds has been described which appears to correspond with the lower and middle portions of the British Series, but does not include any representative of the Norwich Crag or of the later Pliocene deposits in England. This succession, as interpreted by the researches of Messrs. Van den Broeck, Dr. Lorié, and Mr. Harmer,²¹ is as follows:—

4. Amstelian.
3. Scaldisian or zone of *Neptunea antiqua*.
2. Casterlian or zone of *Isocardia cor*.
1. Diestian or zone of *Terebratulula grandis*.

The Diestian Sands occupy a position similar to that of the Lenham Beds, and are only found on the high ground along the southern side of the Belgian basin, occupying a considerable area near Louvain and Diest, but not extending far to the northward.

Near Antwerp are beds which contain a fauna similar to that of our Coralline Crag. At the base is a pebble bed covered by a blackish sand yielding sharks' teeth, *Cyprina rustica*, and *Cardita senilis*; this passes up into pale greenish-grey sand, from which above sixty species of shells have been obtained, the most abundant being *Isocardia cor*, *Astarte Omalii*, *A. corbuloides*, *Lucina borealis*, *Ringicula buccinea*, and *Turritella incrassata*, with bones of *Balæna* and *Balenoptera*.

This zone is succeeded by the Scaldisian, which consists of red and grey sands similar to our Red Crag, and containing many of the same shells, such as *Tritonofusus gracilis*, *Neptunea contraria*, *Voluta*

Lamberti, *Nassa reticosa*, *N. labiosa*, *Purpura tetragona*, *Pecten maximus*, and *P. Gerardi*. These beds are regarded by Mr. Harmer as the equivalents of the Walton Crag; he points out that *Neptunea contraria* is as abundant as in the English Beds, while no specimen of the dextral form *N. antiqua* has been found in the Scaldisian.

No newer beds are found near Antwerp, but borings in Holland, and especially at Utrecht and Amsterdam, have traversed a great thickness of Pliocene, and prove that all the zones thicken greatly toward the north. Thus the Utrecht boring was carried to a depth of 1198 feet without reaching the base of the Pliocene, and this depth is divided as follows by Mr. Harmer:—

	Feet.
Recent and Pleistocene deposits	513
Pliocene { <i>Amstelian</i> , yellow sands	262
{ <i>Scaldisian</i> , grey glauconitic sands	123
{ <i>Casterlian</i> , grey glauconitic sands	300
	<hr/> 1198

Here, therefore, the Pliocene Series is probably at least 700 feet thick. The shells obtained from the Amstelian include *Nucula Cobboldia*, *Yoldia lanceolata*, *Cardium edule*, *Cardium grælandicum*, *Tellina pretenuis*, *Macra subtruncata*, *Mya arenaria*, and *Littorina littorea*, an assemblage which corresponds to that of the later parts of the Red Crag.

2. France

In the north-west of France there are a number of small patches of reddish sand and blue clay containing a marine fauna which is claimed to be Upper Miocene by Mr. Dollfus, but which has generally been regarded as Pliocene, and the latter view is supported by Mr. C. Reid. These tracts occur, some in the Cotentin, near Carenton and Valognes; some in Ile et Vilaine, near Rennes and Redon; and some still farther south, both north and south of the valley of the Loire. According to Mr. Dollfus the fauna is substantially the same at all localities. *Cardita striatistrina*, *C. aculeata*, *Venus fallax*, *Nassa prismatica*, *N. mutabilis*, and *Turritella incrassata* are some of the characteristic shells.

In the Cotentin the basement-bed is a layer of rolled pebbles with teeth and bones of Miocene and Eocene animals, together with shells of *Terebratula grandis*. This bed is overlain at Gourbesville by sands, and at St. Martin d'Aubigny by greenish clays, and the faunas of these two deposits are not quite the same. Mr. Reid states²² that of 143 species from Gourbesville 91

occur in the Coralline Crag, and that 85 per cent of the whole are living species, which is about the same proportion as in the Red Crag. The clays of d'Aubigny, on the other hand, have only 50 per cent of living species, and contain a larger number of southern species which give them a different and older aspect; but the difference may be due to the different conditions under which the two deposits were formed rather than to difference of age.

It seems probable, therefore, that all these deposits are of about the same age as the Lenham Beds and the Diestian of Belgium, and that it was by connection between the Atlantic and the Belgian Seas across the north of France that the southern species of Mollusca made their way eastward.

In Central and Eastern France the Pliocene deposits are mainly of lacustrine and fluvial origin, but these yield assemblages of mammalian remains by means of which they can be referred to one or other of the three stages of the series. Thus the earliest of these assemblages is that found in the ossiferous breccias of Mt. Luberon and Cucuron in Vaucluse; these beds contain many of the same species as occur in the Pontian of Eastern Europe, especially *Hipparion gracile*, *Rhinoceros Scheiermachi*, *Palæoryx Cordieri*, *Helladotherium*, and *Dinotherium*.

In the Auvergne district the general succession may be tabulated as follows:—²³

Upper	{ Plateau basalts with tuffs and breccias containing bones of <i>Elephas meridionalis</i> .
Middle	{ Stratified deposits of Perrier and Le Puy. Upper phonolite and hanye andesites.
Lower	{ Andesitic trachytes and porphyritic basalts with intercalated breccias.

The stratified beds of Perrier overlies the Miocene (see Fig. 194), and have a conglomerate at the base containing bones of *Mastodon arvernensis* and *Machærodus cultridens*, succeeded by cenerites and sands, the former embedding leaves of plants which comprise maple (*Acer polymorphum*), beech (*Fagus phocenica*), and a bamboo (*Bambusa lugdunensis*). These beds are overlain by a breccia of trachyte fragments, among which are bones of *Elephas meridionalis*, *Equus stenonis*, and *Gazella Julieni*; while in Le Puy pebbly sands beneath the basalts have yielded *Rhinoceros etruscus* and *Hippopotamus major*.

Farther south we find a more complete succession of stratified deposits, without volcanic intercalations, and including a thick marine Placentian stage. These beds extend from near Lyons southward along the valley of the Rhone and spread out in Provence. The general succession is as follows:—

Sicilian—Alluvial pebbly sands with *Elephas meridionalis*.

Astian—Yellow sands with *Mastodon arvernensis*.

Placentian { Sands and marls with *Potamides Basteroti* (160 feet).

{ Marls with *Nassa semistriata*, *Arca diluvii*, etc. (500 feet).

Pontian { Marls of Bollène, with *Congeria simplex* and *Melania Matheroni*, lying unconformably on the Miocene (100 feet).

3. Italy

When the Pliocene is followed eastward into Liguria, the marine deposits are still thicker, presenting a series of marls and limestones over 600 feet thick, and representing the Pontian, Placentian, and Astian, and abounding in fossils. These beds are overlain by 300 feet of yellow sands with few fossils, but these also are of Astian age, and no marine deposits of Sicilian age occur in Northern Italy; near Asti, however, and other places there are fluviatile sands and gravels containing bones of *Elephas meridionalis* and other Upper Pliocene species.

Pliocene deposits occupy large tracts on both sides of the Apennines and are well displayed in and near Rome. They cover about half the island of Sicily, and are largely developed in Calabria. In these southern areas they are over 2000 feet thick and rise to a height of 4000 feet above the sea, consisting almost entirely of marine deposits, the succession being as follows:—

Sicilian, 300 feet	{ Calcareous sands of Palermo with many fossils, including northern species, such as <i>Buccinum granlandicum</i> , <i>Mya truncata</i> , and <i>Cyprina islandica</i> .
Astian, 700 feet	{ Yellow sands with <i>Pecten opercularis</i> , <i>P. varius</i> , <i>Pectunculus pilosus</i> , and other shells.
	{ Limestone and calcareous sand with <i>Amphistegina</i> .
Placentian, 900 feet	{ Limestones with <i>Aporrhais pespelicani</i> and <i>Pecten jacobæus</i> .
	{ Blue marls with <i>Nassa semistriata</i> .
	{ Sands with Bryozoa and Brachiopods (<i>Terebratulina</i>).
Messinian, 300 feet	{ Foraminiferal marls and limestones with <i>Ostrea cochlear</i> and <i>Clypeaster pliocenicus</i> .

In the Val d'Arno there is an extensive lacustrine deposit over 700 feet thick, the lower part including beds of lignite with plant-remains and the bones of a tapir; the upper part yielding the bones of many mammalia of Upper Pliocene age, such as *Elephas meridionalis*, *Rhinoceros etruscus*, *Equus stenonis*, with antelopes, deer, a bear (*Ursus etruscus*), an ape (*Macacus florentinus*), and three species of *Machærodus* (sabre-toothed tigers).²⁴

4. Austria and the Balkans

Pontian.—In Austria the Sarmatian Clays are overlain by the *Congeria* Beds or Pontian stage, consisting of sandy marls and

clays which have a thickness of more than 300 feet. The prevalent shells are species of *Congeria*, *C. conglobosa* occurring in the lower part, with *C. triangularis* and *C. rhomboidea* in higher beds, with species of the peculiar *Cardiidæ*—*Adacna* and *Monodacna*—like those of the Caspian Sea. These *Congeria* Beds extend eastward through Hungary, Croatia, Roumania, and Southern Russia to the Caspian Sea and Lake Aral, which lakes, together with the Black Sea, may be regarded as remnants of the ancient and much larger Pontian Sea.

In Greece the *Pikermi* Beds are a lacustrine deposit of the same age; they consist chiefly of red marly clays with land and freshwater shells, varied by layers of sandy marl and lenticular beds of pebbles; in the clays are several layers of mammalian bones.²⁵ These beds are part of a formation which has a wide extension in Attica and is regarded by Fuchs as of Pliocene (not Miocene) age, as the freshwater beds overlies deposits which contain marine shells of Pliocene species (*Pecten benedictus*, *Ostrea undata*, and *O. lamellosa*). The bones are mostly separate and some are broken, but many complete limbs occur with the bones in their natural position, as if they had been washed down from higher ground during heavy floods. The principal members of this fauna have been mentioned on p. 588. Similar deposits have been found in Eubœa and in the island of Samos.

Placentian.—In Austria the Pontian Clays are succeeded by some lacustrine beds with land and freshwater shells, but these are more fully developed in Croatia, Roumania, and Bulgaria, where they are known as the *Paludina* Beds. The lower part of these contain smooth rounded forms of *Viviparus* (= *Paludina*), but in the higher beds they are carinated. *Mastodon arvernensis* has been found in the lower beds. Similar beds extend through Southern Russia to the Caspian Sea and are well exposed near Odessa, where beds containing *Prosodacna* and *Dreissensia* overlies the *Congeria* Beds and are themselves succeeded by the "Paludina Beds."

Astian and Sicilian.—Newer Pliocene deposits, both of marine and lacustrine origin, occur at different places all over the same eastern region, and marine Pliocene Beds occur also in Cyprus and Asia Minor, but their stratigraphy has not yet been sufficiently investigated for the recognition of stages or zones.

5. Germany

No marine Pliocene deposits occur in Germany, but at Eppelsheim near Worms there are sands and gravels, overlying Miocene Beds, which have yielded a Pliocene mammalian fauna

resembling that of Pikermi, but without *Helladotherium* or the antelopes.

E. HISTORY OF THE PLIOCENE PERIOD

At the beginning of Pliocene time all the mountain ranges of Central and Western Europe had been formed, and the greater part of the European region was in the condition of dry land, though the coast-lines were not the same as those of the existing continent. The British area was still a compact and extensive tract of land, extending northward beyond Ireland and Scotland, but it seems to have been separated from France and Belgium and must therefore have been a large island. We have seen that the southern aspect of the fauna of the Diestian and Coralline Crag Seas makes it almost certain that there must have been a connection with more southern seas, and this connection most probably lay along the line of the English Channel and through Normandy to the country between the Vilaine and the Loire, where it opened into the Atlantic. This matter is more fully discussed in my *Building of the British Isles* (1911).

In the south of Europe the Mediterranean Sea still existed, but probably opened southward through Egypt, for there is no evidence of any opening across Spain or by the Straits of Gibraltar until the time of the Sicilian Beds, when northern species of Mollusca first entered the Mediterranean area. This Mediterranean only covered small parts of Southern France, but seems in Placentian time to have extended up the valley of the Rhone, converting it into a sort of fiord. Thence its northern shore passed along the feet of the Maritime Alps and round the great basin of Northern Italy, the whole of that country except the ridge of the Apennines being covered by the Lower Pliocene Sea, together with nearly the whole of Sicily and parts of Northern Africa, especially in Tunis, Tripoli, and Egypt.

East of this sea, and separated from it by the ridge of the Dinaric Alps and the Highlands of Montenegro and Albania, lay the large inland sea of the Ponto-Caspian region, which extended from the Vienna basin on the west to and beyond the Sea of Aral on the east. Whether the deposits of Pontian age in Greece and the Ægean area were formed in a gulf of this sea or in separate lake-basins is at present uncertain, but the probabilities are in favour of the latter view. These conditions continued to prevail in the Pontian area through Placentian time, but the waters of the great lake gradually became more and more fresh, so that the Congerias died out and their place was taken by *Unio*, *Viviparus*, and *Melanopsis*.

The change from the conditions of Lower Pliocene to those of Middle Pliocene (or Astian) time seems to have been produced by a general uplift of what may be termed the central axis of Europe, in other words, across the whole of that part of Europe which lies between the parallels of 40° and 51° ; while further subsidence took place both in the southern Mediterranean and also in the northern region. Thus the Italian area continued to sink, permitting a great thickness of marine deposits to be accumulated, and the Pontian lakes continued to exist, but probably they had shrunk in size. The whole of France and the English Channel became dry land, and all direct communication between the Atlantic and the Belgian Sea was thus cut off; but farther north subsidence was taking place, forming and widening a channel between Scotland and Norway which opened into the Arctic Ocean.

The facts which relate to this gradual formation of the North Sea Basin and to the extension of the great delta of the Rhine may be mentioned more fully. Having regard to the present position of the Lenham Beds, and the progressive overlap of the newer crags toward the north, as well as the great thickness of the Pliocene deposits in Holland, we may infer that the crust movement in the Anglo-Belgian area had the effect of a tilt, which caused a subsidence on its northern side, while its southern Border was raised through at least 780 feet.

Thus all connection with more southern seas was severed. On the other hand, the subsidence to the northward allowed the sea to spread farther north than in the earlier part of the period, and before the epoch of the Newbourn and Butley Crags it would seem that part of the land which had hitherto united Scotland and Scandinavia was submerged, so that an opening was formed into the Arctic Ocean.

The Red Crag is generally regarded as a shore deposit, and by Mr. Harmer it is compared with the shelly banks and beaches which are now being formed all along the coast of Holland. These accumulations of sand and shells are attributed by Dutch geologists to the prevalence of gales from the west, and as no such shell-beds exist now on our eastern coasts this seems to explain the facts, but if such was the origin of the Red Crag we must suppose that in Pliocene time the prevalent gales were from the eastward and not from the westward, as is now the case.²⁶

As the sea extended its area northward and the land rose on its southern border, the valley of the Rhine must have prolonged itself northward over the southern part of the North Sea plain, and we have seen (p. 600) that the Chillesford Beds may possibly

be deposits formed in the estuary of that river. Other indications of a large river flowing from the south present themselves in the Cromer (Forest) Beds, and Mr. C. Reid has carefully examined the stones which compose the gravelly portion of the deposit. He found the collection of pebbles to be such that if the river had flowed from the south, west, or north, it must have brought a very different assemblage. "It seems, therefore, that only from the south-east and east could the stones be derived, and that the river must have been very large is shown by the uniformity of the composition of the gravels at considerable distances apart; if this be the correct reading, the river can be no other than the Rhine, a view held by various writers ever since the Forest Bed was first known."²⁷

With respect to the change in the climate, the fauna of the Diestian Sand and Coralline Crag is that of a rather warm sea, and the mean annual temperature of the surrounding country must have been decidedly higher than it is now in the same latitude. The subsequent exclusion of the warm southerly current doubtless caused a general diminution of temperature, but there were other meteorologic and cosmic causes which operated in rendering the climate more and more frigid, till at length in the Weybourn Crag we find a fauna indicative of a climate somewhat colder than that which at present prevails in Norfolk. This prepares us for the great change which took place very soon after the formation of that bed.

In the Mediterranean area the closing scenes of Pliocene time were connected with the subterranean disturbances which resulted in the formation of the great volcanoes of Etna and Vesuvius and the smaller vents of the Latian Hills. The earliest volcanic eruptions appear to have been submarine, for the Astian and Sicilian deposits of Sicily, Calabria, and Rome include interstratified beds of volcanic ash and sand. It was not, however, till the close of Pliocene time that the greatest discharges began, for the building up of Etna and the elevation of the Pliocene deposits to the levels at which they are now found, *i.e.* more than 3000 feet above the sea, must have taken place in early Pleistocene time.

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CHAPTER XVII

THE PLEISTOCENE SERIES

A. GENERAL CONSIDERATIONS

THE term Pleistocene was used by Lyell to denote the deposits which are newer than the Pliocene and yet not modern enough to be called Recent. But different writers have different ideas as to what deposits should be called Recent. It seems best to consider the Pleistocene period as including all deposits in Europe which are older than those containing metal implements of human manufacture.

Some of these deposits have obviously been formed during a time when the climate became so cold that the higher parts of the country were covered with ice and snow and the North Sea was more or less filled with ice. Such deposits are called Glacial, and the time during which they were formed is known as the Glacial period, or epoch, and sometimes as the "Great Ice Age," while all the subsequent deposits can be classed as "Post-Glacial." This, however, is not a satisfactory division of Pleistocene time, because the Glacial deposits do not extend all over Europe, being limited to its northern parts and to a certain area round the Alps. In other parts of the region fluvial, alluvial, and subaerial deposits were being formed, which are of a more normal character, though some of them exhibit signs of severe climatic conditions.

The Pleistocene deposits cannot therefore be treated as one consecutive series, but must be regarded as including two different sets of deposits, which may be called *Glacial* and *Non-Glacial*, but are only distinct from a regional point of view, some of the one set being contemporaneous with the other set. Again the Glacial deposits, even those of a single country like England, are not easily classified; for they vary so much in different districts and are so irregularly stratified that correlation is difficult. There is of course a general succession in time, and elaborate classifications have been formulated, but these are based upon assumptions and

theoretical views, and must be received with great caution ; for it is obvious that, owing to the special conditions under which Glacial deposits have been accumulated, ordinary stratigraphical principles cannot be applied to them.

Neither are the organic remains which occur in the Glacial deposits to be trusted as implicitly as those of other series of strata, because portions of an older deposit have sometimes been transported and mixed with newer accumulations. Bones of Mammalia are occasionally found in the Glacial Series and more frequently in Non-Glacial deposits, and they do afford a certain criterion of age, as some of them belong to extinct species and they occur in different assemblages which seem to have succeeded one another. In this way three divisions of Pleistocene time have been distinguished, (1) a time when *Elephas antiquus*, *Rhinoceros Mercki* (= *R. leptorhinus*), and *Machærodus* were common animals ; (2) a time when *Elephas primigenius* (the Mammoth), *Rhinoceros tichorhinus*, and *Hyæna spelæa* took their places ; and (3) a period when the Reindeer (*Cervus tarandus*) ranged over the greater part of Europe, accompanied by many other existing species of animals which live now within the Arctic Circle.

Lastly, it was during the Pleistocene period that man appeared in Europe, and one of the special characteristics of man is that he is a manufacturer of implements. Accordingly implements fashioned by the hands of men are found here and there even in early Pleistocene deposits ; the older tools being always made of stone and roughly manufactured, but those of the later phases of the period showing more and more careful shaping and finishing. Stone implements thus afford another means of correlating the Non-Glacial deposits of different districts and countries, but they are rarely found in or under the Glacial deposits.

The division into Glacial and Non-Glacial is therefore the only arrangement under which the Pleistocene deposits can be conveniently described, and this will be adopted in the following pages ; but the reader must remember that the two sets of deposits are more or less contemporaneous.

With respect to the life of the period, it will be convenient to defer giving a list of the Pleistocene Mammalia till we deal with the Non-Glacial deposits in which they are most frequently found, but mention may be made of the marine shells which often occur in Glacial deposits and in beds associated with them. Those which actually occur in boulder-clays are generally broken, but those found in the interstratified sands and gravels are often perfect.

The marine mollusca of Pleistocene times all belong to living species, but those found in the Glacial deposits are such as live

in the seas round the northern parts of our islands, the species of our southern coasts being generally absent. The following are some of the commoner species in Glacial Beds, and some of them are shown in Fig. 201 :—

Gastropoda. *Natica affinis* (clausa), *N. pallida* (=grœnlandica), *Trophon clathratus*, *T. Fabricii*, *Buccinum undatum*, *B. grœnlandicum*, *Bela turricula*, *Turritella communis*, *Scalaria grœnlandica*.

Fig. 201.—GROUP OF PLEISTOCENE MARINE SHELLS.

a. <i>Pecten islandicus</i> .	e. <i>Natica affinis</i> (=clausa).
b. <i>Astarte borealis</i> .	f. <i>Trophon clathratus</i> .
c. <i>Corbicula fluminalis</i> .	g. <i>Scala grœnlandica</i> .
d. <i>Trophon Fabricii</i> .	h. <i>Puncturella noachina</i> .

Lamellibranchia. *Pecten islandicus*, *Leda truncata*, *Yoldia arctica*, *Y. lanceolata*, *Tellina lata*, *T. balthica*, *Astarte borealis*, *A. compressa*, *Panopea norvegica*, *Saxicava rugosa*, *Cyprina islandica*.

B. GLACIATION AND GLACIAL DEPOSITS

Glacial Deposits.—These are the relics of a time when the conditions which are now confined to the Arctic and Antarctic regions, prevailed over the whole of Northern Europe. They are

principally such as result from the action of moving masses of ice (boulder-clays), or from the action of strong currents of water (coarse gravels), but interstratified with these there are sometimes sands, brick-earths, and laminated loams which have been deposited in quiet water and in a more gentle manner.

The chief product of the Glacial epoch is the material known as boulder-clay. There are several varieties of such clay, and it is by no means certain that they have all been formed in the same manner. Some boulder-clays are stiff compact masses of unstratified clay containing numerous stones and boulders, and they seem to have been compacted by the passage of heavy masses of ice over them. It does not follow, however, that they were dragged along beneath the ice in the form of what has been called "ground-moraine." The prevalent view at the present day is that the materials of boulder-clay were enclosed in the moving ice, principally no doubt in the lower portion of it, but embodied in and moving with the ice. Wherever the glacier or ice-sheet melted this "*englacial*" material thawed out, and was dropped to form an unstratified clay full of stones and boulders. It might even accumulate by the thawing of the under surface of stationary ice during a temporary amelioration of climate, and if climate conditions again became severe a renewed movement of ice might take place in such a manner as to pass over such boulder-clays without removing them.

Other boulder-clays are of a looser texture, and are more frequently associated with sands and gravels which contain marine shells, and such clays must either have been formed where ice invaded the sea, or must be the product of an ice-sheet which had passed over a sea floor, or was moving from the sea over the retreating shore of a sinking land.

These shells occur at various heights above the present sea-level from 100 to over 1300 feet, and also far inland, often many miles away from the present coast-line. The question naturally arises whether they are *in situ* or whether they have been transported to their present positions by the agency of ice. When they were first discovered and described they were regarded as proofs of a great submergence, during which the British Isles sank to an extent of more than 1300 feet. Later it was perceived that this was highly improbable, because no evidence of such a subsidence exists in the south of England nor in the north of France; marine deposits in these areas being restricted to coastal belts, and not occurring at more than 130 feet above sea-level.

Latterly glacialists have tried to explain the occurrence of all marine relics at high levels on the supposition that they were

frozen into the base of enormous ice-sheets, which not only filled the basins of the North Sea and the Irish Sea, but were able to take up portions of the sea floor, and carry them up to high levels in England and Ireland. Further it has been maintained that instead of the land being lower and the seas deeper than they are now, the whole of Northern Europe had been raised to a greater elevation than that at which it now stands, and that land-ice was the sole agent concerned in the transport of marine shells as well as of large stones and boulders.

These are extreme views, and the truth probably lies in a modification of them. The idea of the land being at a higher level than it is at present, either at the beginning of the Glacial Period or at the time of maximum glaciation, is a mistake. The evidence only proves that the land had previously been at a higher elevation, *i.e.* in Pliocene and Miocene times, and it favours the conclusion that the land sank as the thickness of ice upon it increased. At the same time it must be admitted that the shells at very high levels may not be exactly *in situ*, and that perfect shells have not been found in sufficient number to prove a submergence of more than 500 or 600 feet. Thus at Clava, near Inverness, there is a shell-bearing deposit with Arctic species at about 500 feet, and overlain by boulder-clay. A British Association Committee, appointed to investigate this and other localities, reported that the molluscs at Clava had probably lived on the spot where their shells are now found.

It is probable, however, that the subsidence was greater in the north than it was farther south, and that while it may have been 600 feet in the latitude of Inverness it was not more than 130 or perhaps 160 feet in the south of England. Even such a moderate subsidence, however, would greatly facilitate the movement of ice-sheets over tracts which are now dry land, and would account for the transport of many rock-fragments from lower to higher levels under 500 feet. In spite of this we are still obliged to admit that there was sufficient *vis a tergo* to force the ice not only over the sea floors but out again and up to considerable heights on the other side. It has also been pointed out that under such conditions shear-planes may have been produced, and portions of the ice thrust forward and upward over parts in front of them. Such upward thrusts have been observed in Spitzbergen at the present day.¹

Glaciation of Rock Surfaces.—In nearly all districts where boulder-clays occur the rock-surfaces which underlie the lowest clays are glaciated, that is to say they are grooved, scratched, and smoothed as they would be by the passage over them of heavy ice, which, when its sole is full of stones and boulders, becomes a gigantic

rasping, graving, and moulding tool. In most cases it is found that the grooves run parallel to the main valleys of a district, and in many cases when the directions are marked on a map it is seen that they radiate outward in all directions from some central mountain tract; but occasionally they run in one direction across some tract of country without any reference to its valley system,

Fig. 202.—MAP SHOWING THE GLACIATION OF SCOTLAND AND THE NORTH OF IRELAND (J. R. Kilroe).

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as if the ice had been locally deflected from its natural course. This system of grooves and striations is often called the glaciation of a district or country.

Thus the plotting of the principal lines of striation in Scotland has shown that country to have been an independent centre of ice-dispersal, and that at the time of maximum glaciation it was wholly

covered by snow and ice which moved outward from the principal water-sheds; the ice-fields of the Central and Northern Highlands forming a confluent ice-sheet which spread out in all directions and descended into the neighbouring seas (see Fig. 202).

The south of Scotland formed another centre of dispersion, the ice flowing off its uplands, moving chiefly in western, southern, and eastern directions, because free movement to the north was blocked by the more northern ice-sheet.

There are, however, exceptions to the coincidence between the direction of the striæ and that of the main valleys; thus the district known as Knapdale in Argyllshire, which rises to 700 or 800 feet above the sea, is glaciated obliquely from north-east to south-west, as if the ice had filled up the valley of Loch Fyne, and had flowed over the ridge to the Sound of Jura. There seems also to have been a time when the ice from the Perthshire highlands went across the Ochil Hills, some of which reach a height of 2300 feet, and these are important facts to remember when the mode of glaciation is considered.

In the north of Ireland again the Glacial striation is not of a simple radiating character. According to Mr. J. R. Kilroe, the striæ can be resolved into two sets, the one set having a general direction from east-north-east to west-south-west across the whole area with local variations to west and south-west in Mayo and Galway, while another set show lines of movement northward, southward, and south-eastward. These facts he interprets to mean that there was first a local snow-field covering all the high ground between Mayo and Antrim and shedding its ice both to the north and the south; but that at the time of maximum glaciation the Irish ice was so dominated by that flowing off the Scottish Highlands that it was forced to move westward (see Fig. 202).

The Lake district and the Welsh mountains were also independent centres, and the glaciers of the former seem to have maintained their radiating onward movement throughout the whole of the Glacial epoch, but their terminal parts were merged into the ice flowing off the south-west of Scotland. In Wales the striæ also have a general radiating arrangement from two centres, the Snowdonian and Merioneth mountains forming one, the Plynlimon Group and the highlands of Central Wales forming the other. Movement to the north and north-west was, however, blocked by the northern ice, so that Anglesey is glaciated from north-east to south-west, Denbigh, Flint, and South Lancashire from north-west to south-east. Consequently the ice of North Wales moved chiefly to the east and south-east, and boulders from the Arenig mountains have been carried eastward into Shropshire and Staffordshire.

The ice from the central ice-field of Wales was also free to flow eastward, southward, and westward, but it seems to have been partially turned aside by the mass of the Brecknock Beacons and

Fig. 203.—MAP SHOWING THE AREAS OCCUPIED BY THE DIFFERENT ICE-SHEETS IN ENGLAND.

to have flowed chiefly in southerly and westerly directions. Thus it overran the whole of the South Wales coalfield, the striæ on the rocks of the northern borders of that area all indicating flow

from the north. Pembrokeshire on the other hand has been glaciated by ice coming in from the Irish Channel (see map, Fig. 203).

C. THE GLACIAL DEPOSITS OF BRITAIN

No classification of the Glacial drifts has yet been proposed which is applicable to all parts of the British Isles. In some areas it is possible to establish a local succession of deposits, but all attempts to correlate those of one area with a similar series in another area have hitherto broken down.

In some districts, such as Aberdeenshire, Norfolk, North Wales, and the south-east of Ireland, there are certainly older and newer boulder-clays, differing in colour and contents, and in some places they are separated by stratified sands and gravels. We may safely infer that such different deposits were formed during different successive phases of the Glacial Period. In Germany the Glacial deposits appear to exhibit a greater uniformity, and it is generally held that there are two boulder-clays, a lower and an upper, and that they indicate two epochs of advance and retreat of the northern ice.

The great variation observable in the Glacial deposits of Britain is doubtless due to their being the product of several distinct ice-sheets coming from different directions. This is especially the case in England, where the influence of no fewer than five ice-sheets can be distinguished (see map, Fig. 203). At present, therefore, the British deposits can only be described in a piecemeal fashion, and brief accounts will be given of those found in the following areas :—

1. Central and Northern Scotland.
2. South Scotland and the north of England.
3. Yorkshire and Lincolnshire.
4. East Anglia.
5. The Midlands.
6. Wales and the West of England.
7. Ireland.

1. *Central and Northern Scotland*

The Glacial deposits of Scotland may be classified as follows, but it is seldom that all the members are found in one locality, and it is probable that the moraines were more or less contemporaneous with the later shell-bearing clays :—

4. Moraines of local glaciers.
3. Shell-bearing clays near the coast.
2. Upper boulder-clays with stratified sands and gravels.
1. Lower boulder-clay or till.

The till is described as a very stiff clay full of stones and boulders, the whole being so hard and compact that it often weathers like a conglomerate. Boulder-clay of this kind occurs up to heights of 1600 feet, and is sometimes over 100 feet thick, being always thickest on the low grounds and thinning away on the highland slopes. The stones and boulders found at any given locality are principally derived from local rocks, and in the lowland clays there are not many stones which have travelled more than a few miles from their parent site; most of the fragments are smoothed and striated, and many are scratched all over, often exhibiting five or six definitely striated surfaces. The local character of the clay is also shown by its variations in colour. Hugh Miller, sen., long ago remarked that red sandstones were covered by red boulder-clay, the grey flags of Caithness by a lead-coloured clay, and the coal-measures of the Lothians by a bluish-black clay; subsequent observations have shown that the clays of these colours do not exactly coincide with the limits of the formations from which they derive their tint, but slightly overlap them in an outward direction.

Thus, though the materials of this inland boulder-clay afford evidence of a certain amount of transport, still its local character is so strongly marked that "whatever may have been its mode of production, it cannot have been carried from a distance, but must have been formed on the whole in the districts in which it is found."

In many places the hard till or boulder-clay above described is covered by deposits of a more varied character, consisting of stratified sand, gravel, and clay; such deposits occupy large areas in the central lowlands between the firths of Forth and Clyde. Associated with these beds or stranded on bare hill-sides are numerous large erratics or isolated boulders, which have usually come from points to the north or north-west of the positions they now occupy, and some have travelled distances of 50 or 60 miles; it is to be noted that such boulders rarely occur in the boulder-clay, though they often lie on it, the travelled stones in the boulder-clay being always of small size.

Along the east coast, from Stonehaven to Peterhead, a very different kind of boulder-clay is found; this is a reddish-brown clay which contains broken marine shells, and often includes seams of fine sand or laminated silt; moreover, its materials appear to have been derived from the southward, from the Old Red Sandstone districts in Kincardine and Forfar, a conclusion which is confirmed by the occurrence of striæ on the rocks below, pointing from south-south-west to north-north-east.^{1a} Near Collieston and Slains this clay rests on stratified sands and gravels which are more

than 50 feet thick and contain numerous broken marine shells, which seem to have been derived from the destruction of Pliocene Beds, comparable to the English Crags. The red clay varies from 10 to 30 feet in thickness and reaches inland up to heights of 300 feet, while pebbly gravels with broken shells range up to 470 feet.

In the basin of the Clyde there are certain deposits which were evidently formed during the last stage of the Glacial epoch. The usual succession of these beds is as follows :—

Clyde
Beds	{	3. Sandy clay or sandy gravel.
		2. Fine grey clay with many perfect shells.
		1. Laminated reddish clay without shells.
Till.		Hard tough boulder-clay with striated stones.

There is always a layer of laminated, stoneless, and shell-less clay between the till and the shell-bearing clay (No. 2), but its thickness varies from 1 to 18 feet. The clay above is a consolidated mud through which many stones, both rounded and angular, are scattered, but its consistency is not that of boulder-clay, and the stones are not glaciated; the shells which occur in it are generally perfect, and are of northern and Arctic species. These clays fringe the Firth of Clyde from Glasgow westward, and pass up the Kyles of Bute to Loch Fyne; they are also found on the shore of Loch Lomond, but do not anywhere extend beyond 50 feet above the sea.

Inland the last phase of the Glacial epoch is marked by the occurrence of terminal moraines in many of the Highland valleys; sometimes several such moraines occur one above another, and huge blocks of rock are often perched on the top of them as well as on the neighbouring slopes, while the course of the glen above the highest moraine is swept clear of all such detritus.

2. *Southern Scotland and North of England*

In this area there were three principal centres of dispersion, one in Galloway, whence confluent glaciers moved outwards from the central granitic hills, another in the Lake District already mentioned (p. 617), and a third on the Hartfell, Ettrick, and Cheviot Hills, from which ice flowed chiefly eastward and southward (see Fig. 202). In each area the northward flow was short, and the main lines of transport were south and south-east. Thus Eskdale granite is found all over Lancashire and Cheshire, and boulders from the fells near Shap have been carried not only down the valley of the Lune, but over the Ingleborough district into Ribblesdale, showing that at one time the ice over-rode hills up to 1500 feet above present sea-level. Another stream of boulders has passed through the Stainmoor pass and through Teesdale to the east coast of Northumberland.²

The whole of Southern Scotland and Northern England below the level of 1600 feet is more or less covered by boulder-clay, which in many places has the same character as the Scottish *till*. The larger boulders embedded in this till are striated *in situ* in the same general direction and with the same firmness and evenness as the striæ on the underlying rocks; thus the till of Northumberland may be likened to one vast irregular "striated pavement." The smaller boulders and stones frequently have their longer axes drawn into the line of glaciation, as if by a heavy dragging force moving contemporaneously with the arrangement of the material. At the surface it is often shaped into sow-backs or *drumlins* stretched in the same direction. All these features of the till are remarkably developed on the watershed among the Bewcastle Wastes, north of Gilsland in Cumberland.³

The composition of the till, again, shows that the outcrops of rock lying in the path of movement—all the way from the red rocks of Cumberland, for instance, to the coaly shales of Newcastle—contributed one after the other their quota of material to the mass of the clay. The texture and colour of the till thus constantly varies—it is bright Indian red on the red rocks; leaden-coloured and clayey on the carbonaceous rocks; sandy where the pale Carboniferous sandstones predominate; brown on the Cheviot porphyry; and when it rests on composite formations such as the Carboniferous limestone series, it never remains for half an acre the same. Among the slopes of the higher hills it is thin, loose, local, angular, and almost morainic-looking; in the valleys and low grounds it becomes dense and well-kneaded up, and contains a larger assortment of boulders; in the lower grounds it is often gravelly and much intercalated with seams of sand, gravel, and laminated clay; but it is the same deposit throughout.

In the south-west of Scotland, and especially in Ayrshire, broken marine shells are found in the boulder-clay up to heights of 1000 feet above the sea, and the precise manner of their conveyance against the outflow of the local ice has not yet been explained.

On the coast of Northumberland and Durham, however, there is a newer or upper boulder-clay limited to the maritime districts, and to elevations under 350 feet. It is divided from the till sometimes by stratified sand and gravel, and sometimes by an eroded junction line. It seems to be the same deposit, very uniform in character, that is found along the sea-board from Aberdeenshire southward, differing from the till by its uniformly reddish colour and the fewness and smallness of its stones.

3. *Yorkshire and Lincolnshire*

When this northern ice reached the Cleveland Hills in East Yorkshire the mass of it was diverted into the Vale of York and, reinforced by contributions from the west, it spread out a confused mass of clays and gravels over the Triassic plain as far south as York and Eserick, where it has left some remarkable terminal moraines. Another lobe of this ice passed down the eastern side of the Cleveland Hills and along the coast to Flamborough Head.

South of York there is a long and fairly broad area which is almost free of boulder-clay, a fact which is not yet fully understood, for there are boulder-clays to the west of it about Wakefield, Barnsley, and Doncaster, and one would have expected these to extend into the plains west of the river Trent.

Boulder-clays occur in East Yorkshire near the coast and over the greater part of Lincolnshire, but they are of two different types; those found on the eastern side of the Chalk Wolds being reddish and purple clays with intercalated marine deposits, while those on the western side are grey and more or less chalky clays.

The Chalky Boulder-clay covers the central parts of Lincolnshire, spreading over the Jurassic Clays east of Lincoln by Tattershall, Horncastle, Wragby, and Market Rasen; and the increase in the amount of chalky matter in the direction of the Chalk Wolds is particularly noticeable, till near these hills it becomes a stony Chalk-marl, and has been burnt for lime in some places. There is, however, very little of it on the Wolds themselves, though its occurrence at Kelstern, near Louth, proves that it originally spread over all levels below 400 feet.⁴

It occurs also in South Lincolnshire, not only on the border of the Fenland district, but on the higher ground to the west, and appears to have formed a continuous mantle which covered even the summit ridges of the Jurassic escarpment and passed southward through Rutland, Northampton, and Huntingdon. The boulder-clay of the high ground between Stamford and Grantham is remarkable for containing huge masses of Lias Marlstone and Lincolnshire Limestone, which have been carried many miles from the spots whence they were quarried by the ice. These blocks appear to have come from the west and north-west. Carboniferous rocks came from the north-west, and Chalk from the north-east, so that several ice-currents seem to have met in this area.

The boulder-clays of the eastern type occupy the area in Yorkshire known as Holderness, and underlie the whole of the eastern lowland of Lincolnshire. In both cases they and the associated sands and gravels are banked up against an ancient

Fig. 204.—DIAGRAM SECTION FROM FAKENHAM TO NEAR CROMER IN NORFOLK. Distance about 18 miles.

f. Chalky Boulder-clay.
e. Sand and gravel.
c. Contorted Drift and Cromer Till.
b. Norwich and Weyborne Crags.
 1. Upper Chalk.

Fig. 205.—SECTION THROUGH PART OF EAST LINCOLNSHIRE (after Searles Wood). Distance about 17 miles.

S.S. Sea-level.
 5. Chalky Boulder-clay.
 4. Hessle and Purple Clays.
 3. Upper Cretaceous Rocks (chalk).
 2. Lower Cretaceous Rocks.
 1. Kimeridge Clay (Jurassic.)

coast-line which is in many places a line of buried cliffs. Such cliffs are intersected by the present coast-line at Sewerby in Yorkshire, and though they are not seen in Lincolnshire their existence is proved by the depth of Glacial deposits found at many places on the east of the chalk-surface. These deposits also enter the valleys of the Wolds, and appear to have mantled the slopes of the hills up to a height of at least 380 feet.

The succession of beds seen in the cliffs near Bridlington and Sewerby is as follows, and is from 60 to 100 feet thick :—⁵

5. The Sewerby gravels.
4. The Hessle Boulder-clay,
3. The Purple Boulder-clay.
2. The Basement Boulder-clay.
1. Chalky gravel and Buried-cliff Beds.

The buried-cliff beds are only seen at Sewerby, where they are banked against the ancient coast-line above mentioned (see Fig.

Fig. 206.—CLIFF-SECTION AT SEWERBY (after G. W. Lamplugh).

8. Sewerby gravel.	4. Blown sand	} Buried cliff
beds.
7. Purple boulder-clay.	3. Rainwash	
6. Basement boulder-clay.	2. Pebble beach	
5. Chalky gravel.	1. Chalk	

206). From the old beach and the overlying rainwash bones and teeth of the following Mammals were obtained : *Elephas antiquus*, *Rhinoceros meroni*, *Hippopotamus amphibius* and *Hyena crocuta*. Elsewhere the chalky gravel appears to form a nearly continuous basal bed. The Basement Clay is of a greenish-grey colour, is sometimes 30 feet thick, and includes twisted layers or patches of sand which contain marine shells ; no fewer than 110 species have been found, and among them are some which no longer live in British waters, such as *Nucula Cobboldie*, *Tellina obliqua*, *Astarte borealis*, *Fusus spitzbergensis*, and *F. Sarsi*.

The Purple and the Hessle boulder-clays have the same characters as in Lincolnshire (see below). The commonest stones in these and the lower clay have been derived from the Carboniferous rocks to the northward, but some have come from the Cheviot Hills,

others from Teesdale and from Cumberland, while a few are identical with rocks in the south and west of Norway.

In Lincolnshire the basement-beds are nowhere visible, but borings prove that there is always a bed of chalk-rubble at the bottom, from 2 to 8 feet thick, and that this rests on a floor of Chalk which is about 80 feet below sea-level along the present coastline. The thickness of the overlying deposits is from 60 to 100 feet, and they are of two kinds, (1) a lower clay of a purplish brown colour (the "Purple Clay"), containing stones and boulders both large and small; (2) an upper clay (the "Hessle Clay") of dull red colour mottled with ashen grey, containing many small stones, pellets of chalk, and bits of coal, but few large boulders.

Near the border of the Wolds patches of sand and gravel are frequent, often resembling beach deposits, and containing many marine shells, some of which are perfect, but most are broken. They include *Mya truncata*, *Corbula gibba*, *Mactra subtruncata*, *Tellina balthica*, *T. lata*, *Cardium edule*, *Cyprina islandica*, *Venus gallina*, and (at Croxton) *Corbicula fluminalis*, which is also abundant at Kelsey in Yorkshire. At Kirmington, and about 80 feet above sea-level, an interesting deposit of laminated silk or warp occurs containing Foraminifera, *Rissoa ulva*, *Scrobicularia plana*, and other bivalves; it resembles the warp formed between tide marks on the present coast, and is overlain by 10 or 12 feet of beach shingle. The occurrence of such undisturbed marine silt in association with the boulder-clays and marine gravels is of much importance.⁶

The correlation of the beds above described with those of more southern counties and the relation of the eastern to the western deposits are debated questions, but two opinions have been expressed, and a third view is also possible. (1) The eastern series may be newer than the western (Chalky Boulder-clay), and therefore later than any deposit in East Anglia; (2) the eastern series may be the older of the two and equivalent to the Lower Glacial of Norfolk; (3) the eastern and western clays may be of nearly the same age but formed by different ice-streams, the one coming from the north and north-east, the other from the north-west.

4. East Anglia

In the north-east of Norfolk, where the most complete sections of the Lower Glacial Beds are found along the coast, the following succession of deposits can be recognised, but there is no place where they can all be seen in vertical succession:—

The Upper or Chalky Boulder-clay.

Lower Group	{	Contorted Drifts (loams and sands).
		Brown Boulder-clay (Cromer Till).
		Arctic plant bed and <i>Leda myalis</i> bed.

Above the Cromer freshwater beds and below the Glacial deposits there are two discontinuous beds which appear to be the oldest Pleistocene Beds in Norfolk.

The **Leda Myalis Bed** is only found between Old Hythe and Cromer, for south of Cromer it either thins out or is cut off by the boulder-clay. The bed consists of fine current-bedded loamy sand, with thin seams of loam and gravel. The fossils are marine, and indicate a depth of 5 or 10 fathoms, as some of the bivalves occur with the valves united in the position of life. All the Mollusca yet found (nineteen species) belong to living species, and they include two characteristic crag shells, *Neptunea antiqua* and *Tellina obliqua*. One of the best exposures is at Runton Gap, near Cromer, where *Leda myalis*, *Mya arenaria*, and *Astarte borealis* may be found in position of life, and the bed is 15 feet thick.

The **Arctic Freshwater Bed** was first described in 1880⁷ by Mr. C. Reid, who then distinguished it from the Forest Bed, and placed it in the Pleistocene Series, because the plants it contains indicate a great change from the climate of the earlier bed. Trees seem to have entirely disappeared, and the plants include the dwarf Arctic birch (*Betula nana*), the Arctic willow (*Salix polaris*), and mosses which now only live within the Arctic circle. It consists of a layer of clay and loam about 2 feet thick, but is not by any means continuous, having only at present been found at three localities on the coast, viz. Beeston, Mundesley, and Ostend, near Bacton. At Mundesley it has yielded freshwater shells, elytra of beetles, and bones of *Spermophilus* (a squirrel-like creature).

The **Cromer Till**, where thickest near Happisburgh, consists of two beds of tough grey unstratified boulder-clay, with an intermediate band of finely laminated and ripple-marked clay. The boulder-clays contain fragments of marine shells, with pebbles and boulders of many kinds of rocks, including gneiss, mica-schist, basalt, red and grey granites, "rhombynporphyr" from Norway, pieces of Carboniferous limestone, and pebbles of hard chalk which have been bored by marine annelids, and subsequently striated.

The **Contorted Drift** is usually a yellowish marly and sandy clay full of stones, so that it is really only a variety of boulder-clay, but it exhibits a rude kind of stratification, and includes knots, patches, and seams of sand and gravel, and the whole has a twisted, contorted, and kneaded appearance. Another remarkable feature of the deposit is the occurrence of large tabular masses of chalk, some of which are 20 to 30 feet thick, and from 100 to 180 yards long. This drift contains boulders similar to those in the till below and many broken shells, the latter being frequent in the

nests and patches of sand, *Tellina balthica*, *Cardium edule*, *Cyprina islandica*, and *Mya arenaria* being the commonest species.

Near Cromer the thickness of the Contorted Drift is sometimes as much as 170 feet, and the contortions are very marked, but southward and south-westward the deposit passes into a set of loams, sands, and fine gravels. Moreover, the underlying Cromer Till appears to thin out, so that over large parts of Norfolk, Suffolk, and Essex the Lower Glacial Group consists only of sands and gravels, with occasional intercalations of laminated loam or brick-earth. These beds were termed "Middle Glacial" by Mr. S. V. Wood. As they are followed to the higher ground in the western parts of these counties, and to the Chalk-escarpment in Cambridgeshire, they thin out and are overlapped by the Chalky Boulder-clay, which then rests directly on the Chalk.

The **Chalky Boulder-clay** is an extension of that already described, and has been formed partly from the detrition of the Chalk and partly from that of the Jurassic rocks, materials from the Oxford and Kimeridge Clays being numerous, and derived fossils, such as *Gryphæa arcuata*, *Gryphæa dilatata*, *Cardinia Listeri*, and *Belemnites abbreviatus*, are not uncommon. In this respect it contrasts with the boulder-clays of the Lower Glacial Group.

This boulder-clay exhibits a fairly uniform character over Norfolk, Suffolk, Essex, Cambridge, Herts, and Middlesex, the most southerly outlier being that on Muswell Hill, north of Highgate; here the clay is of the usual pale colour, and contains occasional fragments of red chalk, which must have journeyed a distance of some 100 miles, for the nearest place whence they could have been derived is Hunstanton in Norfolk. The thickness of this great sheet of boulder-clay is very variable; sometimes only a few feet can be seen, and in other places borings have gone through 100 or 150 feet of it.

Another fact of some importance in connection with the formation of this clay is the occurrence in it of pebbles which have been carried up to a level much higher than that of their source; thus phosphatic nodules derived from the Cambridge greensand have been found at a level of 500 feet above the sea, whereas the outcrop of the parent stratum to the north and west is everywhere under 150 feet.

5. The Midland Area

In the counties of Derby, Stafford, Warwick, and Leicester we find the meeting ground of four different ice-lobes (see map, Fig. 203). Around Derby and Nottingham, and thence south-

east to Leicester, there are two very different kinds of boulder-clay; the one a reddish clay containing stones of Pennine origin, the other a chalky clay with Chalk-flints and Jurassic debris, derived from places to the north-west. This Chalky Boulder-clay is clearly the same as that of Lincolnshire, and it is stated to overlie the Pennine Clay, but according to Mr. R. M. Deeley there is also in the Trent valley a still newer reddish clay with Pennine material, which he calls the Newer Pennine Clay.⁸

There seems also to have been a dispersion of boulders in different directions from Charnwood Forest before the incidence of the ice from the north-west, for such boulders occur at places in Nottingham and Lincoln, as well as near Leicester and Coventry, that is to the north-east and east as well as the south-east and south-west.

In Warwickshire, from near Bromsgrove to the north-east of Birmingham for a distance of some 20 miles, there is a line of boulders which have been transported from Wales, often accompanied by blocks of basalt from the Rowley Hills near Dudley. Lastly, in Staffordshire, round Wolverhampton, Cannock, and Rugeley, and even as far east as Lichfield, there are many boulders which have come from the Lake District and the south of Scotland.

6. *Wales and the West of England*

The Glacial deposits of this district are also divisible into two sets, the one set consisting of detritus which has come from the north and has been transported by ice through or over the Irish Sea, while the other set consists entirely of Welsh material and has been carried by the glaciers which issued from the Welsh mountains (see p. 617). The following account of the Glacial Drifts of Lancashire and Cheshire has been compiled mainly from the writings of Mr. Mellard Reade⁹ and Dr. A. Strahan.¹⁰

The whole of the lower parts of Lancashire, Westmoreland, Cheshire, and North Shropshire, from Coniston and Windermere southward and inland up to heights of 500, and in some places 600 feet above sea-level, is covered by a nearly continuous mantle of boulder-clay, which is only broken in places where Triassic or Carboniferous rise up through it. This boulder-clay, however, is not a solid mass like the *till* of Scotland and Northumberland, but consists of irregular masses or sheets of stony clay with local intercalations of stratified sand and gravel.

The deposits are in fact very like those of East Yorkshire and Lincolnshire, for the lower clays are generally purplish brown, and the upper clays resemble the Hessle Clay in being streaked

Fig. 207.—SECTION ALONG PART OF THE CLIFFS NEAR BLACKPOOL (by Mellard Reade). Distance about $\frac{3}{4}$ mile.

A.B. Red Boulder-clay.

C.C. Stratified Sands and Gravels.

D.E.H. Brown Boulder-clay.

with grey and in containing fewer stones. A good section of these drifts is exposed in the cliffs near Blackpool and is represented in Fig. 205).

Both the boulder-clays and the sands frequently contain marine shells, generally broken, but sometimes perfect, and also abundance of Foraminifera. Moreover, the Gastropod shells are seldom filled with clay or red sand, but generally with a fine white sand or silt which is full of Foraminifera, showing that they have been picked up by the ice from silty shores and sea-bottoms, and these silt-filled shells are just as common in the boulder-clay near Macclesfield, at 600 feet, as they are near the coast. Near Macclesfield, too, there are sands with the same species of shells at a height of 1200 feet above the sea.

The stones and boulders in these clays have come principally from the Lake District and the south of Scotland. They include granite from Eskdale and granophyr from Buttermere, other granites from Galloway, rocks from the Borrowdale Volcanic Series, Silurian Grits, and Carboniferous limestones. Mixed with these in smaller numbers are blocks of Triassic sandstone and flints, which latter must have come from Antrim or from the west of Scotland. The finer material has, however, been largely derived from the Triassic sandstones and clays which underlie the Glacial deposits, and doubtless extend far to the west and north-west below the floor of the Irish Sea.

These deposits fill up and conceal the inequalities of a deeply sculptured pre-Glacial surface. The lakes of Coniston and Windermere are merely the upper ends of pre-Glacial valleys, the lower reaches of which are filled with Glacial drift, and where these old valleys open into Morecambe Bay the valley bottom is probably 200 or 300 feet below the present sea-level, for in Furness one such valley descends to 460 feet below sea-level and is filled with drift.

Southwards these deposits sweep over the

Cheshire plain into Shropshire and over the lower parts of North Wales up to heights of 400 and 500 feet above the sea; while accumulations of sand and gravel with marine shells occur at still higher elevations, up to heights of more than 1200 feet on both sides of Wales. Thus, on the summit of Moel Tryfaen, a hill overlooking Carnarvon Bay, with a height of 1350 feet, there is an extensive deposit of stratified sand and gravel containing marine shells, more than sixty species having been obtained. Among the most abundant of these are *Tellina balthica*, *Cardium edule*, *Astarte borealis*, *Cyprina islandica*, and *Turritella communis*. It is irregularly overlain by boulder-clay, and both deposits contain erratics from Cumberland and Scotland, as well as Chalk-flints which came probably from Ireland. These flints, as Mr. Mackintosh observes, have travelled to a higher level than their source, for the highest parts of the Irish chalk are between 900 and 1000 feet.¹¹

Similar shell-bearing gravels have been found by Mr. Mackintosh at heights of 1000 to 1230 feet on the east side of the hills near Minera in Denbighshire; here also Eskdale granite, Cumberland felstones, and Chalk-flints are mixed with the debris of local rocks, and all are well rolled and rounded as if they had formed part of a sea beach. Another similar deposit of shelly sand and gravel occurs at Gloppe, near Oswestry. Within this Welsh area, however, we find tracts and patches of another kind of drift, which is clearly the product of Welsh ice, and wherever the two are in juxtaposition the local drift always lies underneath the deposits left by the northern ice. This is well shown in the cliffs of Colwyn Bay, where the following succession is visible:—¹²

		Feet.
Newer	4. Brown boulder-clay with broken shells and some northern erratics	8 to 12
	3. Obliquely stratified sands resting on an eroded surface	6 to 12
Older	2. Cream-coloured till in discontinuous patches	0 to 2
	1. Hard bluish-grey till packed full of stones derived from the Carboniferous and Silurian rocks of Wales seen for	6

Most of Central and Southern Wales was covered by another ice-field, its centre of accumulation being the high ground which extends from Plynlimmon southward and eastward through parts of Cardigan, Brecknock, and Carnarthen, and rises in many places to over 1800 feet. The thickness of the ice generated on this area was such that the ice-flow was only partially turned aside by the great mountain masses of the Brecknock Beacons and the Black Mountains, and was actually able to override the northern escarpment of the South Wales Coalfield. Proof has

recently been found¹³ that a great mass of ice passed down the valley of the Towy, but that only its lower part followed that valley westward, the upper ice-layers escaping southward over the escarpment on the southern side.

Much boulder-clay occurs in the track of this ice-sheet from heights of 1500 feet downward, that around Plynlimmon being described as a stiff blue clay or till crowded with rock-fragments of all sizes up to blocks of several tons weight. In South Wales much of it is coloured red by the debris of the Old Red Sandstone. In Glamorgan it passes southward into coarse angular gravel, and finally near the coast into roughly stratified gravels with rounded but striated stones. The interest of the last is increased by the fact that they overlie certain raised beaches so that the beach-material with its marine shells and the marine sand of the caves with the mammalian bones are thus proved to be of Glacial age.¹⁴ The shells are of recent species, but the mammals include *Elephas antiquus*, *Rhinoceros mercki*, *Bison prisus*, *Hyæna spelæa*, and *Ursus spelæus*.

In Pembrokeshire, however, there is quite a different set of Glacial deposits. Those of Northern Pembroke between Cardigan and St. Bride's Bay have been examined by Dr. T. J. Jehu,¹⁵ who found them divisible into (1) a lower boulder-clay, (2) intermediate sands and gravels, (3) an upper boulder-clay. The first is a tough bluish-grey clay containing boulders of Carboniferous Limestone, of rocks from the south-west of Scotland and many Chalk-flints, together with many broken marine shells. It occurs in patches up to 600 feet above sea-level.

The sands and gravels frequently contain marine shells which are generally broken, but some are perfect. Most of the species are such as now live in the Irish Sea, but some are Arctic forms, e.g. *Trophon clathratus* (common), *T. scalariformis*, *Astarte compressa*, and *A. arctica* (= *borealis*); while the commonest shell is *Pectun-glycimeris*. These marine sands occur up to 640 feet.

The upper clay is of a yellowish-brown colour and is best seen in the bays on the coast. The included stones are well scratched and are mostly from northern sources. It is sometimes 40 feet thick, but in places it passes into stony rubble.

In South Pembroke the deposits are similar,¹⁶ and near Nolton on St. Bride's Bay a mass of brown boulder-clay fills up a valley and forms cliffs which are 50 to 60 feet high; it includes flints and many broken marine shells. Isolated transported boulders also occur all over the country, and their disposition shows that the ice-movement was from the north-west; many come from distant sources.

7. Ireland

Ireland is largely covered by Glacial deposits, about which much has been written, but no comprehensive account of them has yet been published. Enough is known, however, to make it obvious that they were accumulated under the same conditions as those of England; those of Northern and Eastern Ireland indeed greatly resemble the drifts of Western England, but those of the central and western districts constitute rather a different type.

The central plain of Ireland "is largely covered by a widely spread mass of drift, consisting of dark sandy clay with pebbles and blocks and occasional beds of sand and gravel, which are sometimes very regularly stratified. The great majority of the pebbles are rounded fragments of Carboniferous limestone, whence the deposit usually goes by the name of the Limestone Drift. This deposit rests not only on the limestone, but sweeps up on to the flanks of all the hills which rise from the central plain. In such case the Limestone gravel (often) becomes largely mingled with the detritus of the rocks of which the hills are made, . . . but gravel almost entirely composed of limestone pebbles is found up to heights of 1200 feet on the granite mountains south of Dublin. It spreads across the lower part of this granite range, and runs down by Bray into the county Wicklow, where it is covered by beds of sand and marl that spread through Wicklow and Wexford over all the low grounds between the mountains and the sea-coast" (Jukes).

In some cases this Limestone Drift overlies a deposit composed entirely of local rocks, as in Glenbarrow, on the northern flank of the Slieve Bloom. Here at a height of 800 feet the river-cliff, 120 feet high, exhibits the following succession :—

	Feet.
Coarse drift with limestone boulders	50
Fine laminated sand	20
Rubbly sand, with angular blocks of Old Red Sandstone, the same rock lying below	50

On the north-east coast there are deposits similar in all respects to the low-level drifts of Lancashire, consisting of red and brown boulder-clays, with frequent intercalations of sand containing marine shells. Cliff-sections of such bed are frequent along the coasts of Antrim and Down, and their marine origin is proved not only by the shells in the sands, but by the presence of *Leda pernula* and *Leda minuta* with attached valves in boulder-clay at Woodburn Glen, near Belfast.¹⁷

Southwards these reddish clays appear to overlie the Limestone Drift, as seen in the cliff-sections at Killiney and Ballybrack, south

of Dublin, and they attain a great thickness near Carlow, where a colliery shaft traversed 89 feet of stiff red clay with stones of various kinds overlying 33 feet of Limestone Drift.

Drifts with marine shells occur again in Wicklow and Wexford, chiefly below 600 feet, but on Three Rock Mountain in Wexford they occur at a height of 1300 feet, and include some more southern forms, as *Dosinia lincta*, *Venus striatula*, and *Venus casina*.

No notice of Irish drifts would be complete without a reference to the long winding banks or ridges of gravel which are known as eskers. These ridges often rest on the surface of the other Glacial deposits, and from these the materials composing them have been chiefly derived. They often extend in sinuous lines for many miles, but are confined to the plains and low grounds, not extending above the 400 feet contour. They may therefore be regarded as among the latest of the Pleistocene deposits, but the occurrence of large boulders on these banks shows that ice was still present.

Morainic mounds occur in some of the valleys of the more mountainous regions, and testify to the existence of small valley glaciers during the last stage of the Glacial period.

D. THE GLACIAL DEPOSITS OF EUROPE

Ice-extension.—The principal centre of ice-dispersion in Europe was the Scandinavian region. The striated rock-surfaces of Norway and Sweden show that a great snow-field accumulated on the highlands of those countries, forming ice-sheets which radiated outwards in all directions from the central axis of the Scandinavian chain. It has also been shown that the ice passed over mountain ridges which are 2700 feet high, so that the ice-sheet in such places must have been at least 3000 feet thick, and some authorities think 5000 feet a probable estimate of its maximum thickness.

To the west and north-west this ice-sheet must have advanced far into the Atlantic before terminating in ice-cliffs like those of the Antarctic ice-sheet of the present day. South-westward it passed into the basin of the North Sea, and is believed to have crossed it so as to impinge upon the eastern coast of England. Southward it certainly crossed the Baltic, which is a shallow sea, and invaded the plains of Holland, Germany, and Russia. Eastward it not only crossed the Gulf of Bothnia, but passed up the Gulf of Finland and over Northern Russia to the Ural Mountains, and south-east into the very centre of the Russian plain (see Fig. 208).

In the North Sea it was met by the independent and smaller ice-sheet formed by the eastern part of the Scottish ice; and the

southern limit of the confluent and continuous ice at the time of its maximum extension, whether floating or resting on sea-floors, is shown in Fig. 208. This southern limit passes through the Bristol Channel and up the valley of the Severn, then across England to that of the Thames, through Belgium by Brussels and Dusseldorf to the foot of the Westphalian Hills; round the Hartz Mountains (which are glaciated to a height of 1470 feet) to the Erz Mountains and the Riesen and Sudeten ranges, passing by Cracow and Vladimir into the basin of the Dnieper and out again in an irregular line through Central Russia.

Glacial Deposits.—Many Swedish and German geologists have endeavoured to eluce some definite order of succession out of the congeries of Glacial deposits which covers such a large part of their respective countries. Most of the Norwegian and Swedish geologists recognise two boulder-clays, a lower bluish clay and an upper clay which is generally of a yellow colour, but in many parts of the region it seems difficult to distinguish them. In Scania, however, the distinction is more clearly marked by the frequent interposition of stratified sands and gravels, and sometimes of laminated clay containing remains of the dwarf birch and other plants. There are also long continuous ridges of morainic material, one behind the other, which are regarded as marking successive pauses in the recession of the ice-sheet.

In Germany the evidence for two distinct boulder-clays seems to be stronger, and some find reason to believe in a third. The Lower "Diluvium" is the most extensive, and is described as a bluish or brownish clay containing many boulders of Scandinavian origin, and it is the southern border of this clay which is shown on the map (Fig. 208). Above it in many places are stratified deposits, generally sands and clays with occasionally beds of peat; these contain plant remains and also the bones of *Elephas antiquus*, *E. primigenius*, *Rhinoceros tichorhinus*, *Cervus megaceros*, and *C. elaphus*. The plants in these beds are specially remarkable because they include not only pines and firs, but leaves of the aspen, poplar, oak, hornbeam, ilex, *Trapa natans*, and a water-lily (*Cratoppleura*), the assemblage indicating quite a temperate climate no colder than that of Germany at the present time.

The Upper Diluvium (or boulder-clay) covers Denmark, Schleswick-Holstein, Northern Germany, and the Baltic provinces of Russia, and is associated with mounds and ridges of terminal moraines which mark the final stages in the retreat of the ice-sheet. One such ridge has been traced from near Neustrelitz in Mecklenburg, south-eastward to Oderberg, a distance of 35 miles, and probably reaches still farther. Borings have shown that the

combined thickness of Glacial deposits on the German plain is variable, as might be expected, but that it is sometimes 300 feet and in a few places even more.

The Swiss Glaciers.—The refrigeration of climate which brought Arctic conditions into Northern Europe was also felt in Switzerland and caused a great extension of the Swiss glaciers, till they not only filled their valleys, but coalesced with one another, and spread out over the plains which lie both to the north and south of the Alps. Thus the glacier of the Rhone spread across the plains of Geneva and Neuchâtel onto the flanks of the Jura Mountains, where it left a long line or belt of transported boulders at an average height of 800 feet above the lakes. Similarly the glacier of the Rhine spread out far beyond the Bodensee (Lake of Constance), passing northward and eastward into the drainage area of the Danube.

As in Germany so in Switzerland there is evidence of two distinct Glacial epochs or advances of the glaciers, separated by an interval of temperate climate. The older deposits are coarse gravels and a kind of boulder-clay or argillaceous moraine. The inter-glacial deposits are fluviatile gravels and sands with beds of lignite at Dürnten, Utznach, and other places, which yield leaves of plants and trees of the same species as now live at these localities, together with bones of *Elephas primigenius*, *Rhinoceros etruscus*, *Ursus spelæus*, and *Bos primigenius*. These beds rest in places on the older moraines, and are overlain by newer moraine-stuff.

Of still later date than the last advance of the glaciers are the terraces of lacustrine deposit at 150 feet above the Lake of Geneva, which prove that the lake has been lowered to that extent since the retreat of the ice during the erosion of its valley by the ex-current river (the Rhone).

E. NON-GLACIAL DEPOSITS

1. Classification and Fauna

Relative Age.—Under this head we group those Pleistocene deposits which have not been accumulated by moving ice and are not interstratified with boulder-clays. The principal deposits of this kind may be catalogued as follows:—

1. Clay with Flints.	4. Lacustrine Deposits.
2. Plateau Gravels.	5. Cave Deposits.
3. River Gravels.	6. Raised Beaches.
	7. Alluvial Levels.

These deposits are chiefly found outside the glaciated areas,

but some of those classed as Plateau gravels occur within these areas and overlie the higher boulder-clays; moreover it has been proved that some of the raised beaches and some of the Cave deposits are of Glacial age. Lastly, the assemblage of mammals found in the older river deposits is the same as that which is regarded as early Pleistocene (see p. 612).

Again, the older river gravels and the older cavern deposits appear to be of about the same age, and in both the stone weapons of Palæolithic man are associated with the bones of many extinct animals. In some places it seems possible to distinguish two Palæolithic horizons or ages, an older of roughly made implements associated with *Elephas antiquus*, and a newer of more finished weapons for which the name *Mesolithic* has been proposed. Some authorities recognise a third age, that in which remains of the reindeer are abundant, associated with a special type of flint implements. If the latter is in real succession and not a mere local variation the Pleistocene (non-Glacial), succession may be tabulated as follows:—

4. Neolithic, the age of domesticated animals.
3. } Mesolithic { the age of the reindeer (*Rangifer tarandus*).
2. } { the age of *Elephas primigenius* and *Rhinoceros tichorhinus*.
1. Palæolithic, the age of *Elephas antiquus*.

In France another scheme of classification is employed, all the rougher implements being called Palæolithic, but classed according to type and finish in three groups, the Chelléan or Acheulian, the Moustérian, and the Magdalenian. Of these the first corresponds with the restricted Palæolithic in the above table, and the two latter with the Mesolithic.

Fauna.—The mammalian fauna consists first of a number of species which are common to all or most of the phases of the period, and secondly of certain groups of species which are either restricted to one epoch or phase, or are much more abundant in the deposits of that phase. Again, many of the Pleistocene animals are survivals of the later Pliocene fauna, and of these some became extinct before Neolithic time, and some still continue to exist either in Europe or Asia.

The oldest assemblage (Palæolithic) includes *Elephas antiquus*, *Rhinoceros mercki*, *Rh. leptorhinus*, *Hippopotamus major*, *Ursus spelæus*, *Machærodus latidens*, and *Trogontherium Cuvieri*.

The Mesolithic implements are associated with *Elephas primigenius*, *Rhinoceros tichorhinus*, *Cervus giganteus* (= megaceros), *C. elaphus*, *Felis spelæa*, *Canis lagopus* (Arctic fox), *Equus caballus*, *Saiga tartarica* (an antelope), *Arctomys marmota* (the Marmot), and species of *Spermophilus*.

The Neolithic fauna is very different from the above, and includes only one extinct species (*Cervus giganteus*), though there are, of course, many animals which have subsequently become extinct in Britain, such as the reindeer, brown bear, wolf, wild boar, and beaver.

Palæolithic man was a hunter only; Neolithic man was a herdsman and agriculturist, and he introduced several domesticated animals, such as the dog, sheep, goat, pig, and short-horn cow.

Fig. 209.—PLEISTOCENE LAND AND FRESHWATER SHELLS WHICH ARE NOW EXTINGUISHED IN BRITAIN.

(Reproduced by permission of Mr. B. B. Woodward and the Council of the Geologists' Association.)

- 1, 2. *Unio littoralis*.
- 3, 4. *Corbicula fluminalis*.
5. *Pisidium astartoides*.

6. *Pisidium amnicum*.
7. *Helix (Eulota) fruticum*.
8. *Hydrobia marginata*.

The molluscan fauna of the older Pleistocene deposits, *i.e.* the fauna of the freshwater deposits, is also interesting, for it includes a few extinct species and a certain number which no longer live in Britain, though most of them still exist in Europe or Asia. Prominent among these is *Corbicula fluminalis*, a species which is extinct in Europe but still lives in the rivers of North Africa; another is *Vivipara diluviana*, believed to be entirely extinct, as is

also the allied species *V. clactonensis*; *Neritina grateloupiana*, found in the Thames valley, is also extinct though allied to the modern *N. danubialis*. A common shell in the older river gravels is *Unio littoralis*, which is extinct in Britain but still living in Europe. Among land shells there is *Helix fruticum*, now only found alive in Central Europe, and *Clausilia pumila*, found at Barnwell, near Cambridge, but now only living in parts of Northern Europe and in Silesia. *Hydrobia marginata* and *Pisidium astartoides* are other species found in British Pleistocene deposits but not now living in Britain. These and some of the above are shown in Fig. 209, for the use of which I am indebted to Mr. B. B. Woodward.

2. British Deposits

As it would be impossible within the limits of this volume to give anything like a comprehensive account of the clays, gravels, cave-earths, raised beaches, and other non-Glacial deposits in Britain, only a few examples will be described.

Clay-with-Flints.—This is a deposit or accumulation of indefinite age, occurring at high relative levels and mainly composed of materials derived from the Eocene clays and sands; hence it only occurs in the south of England and the north of France.

Its typical form is that of a stiff reddish-brown clay containing a large number of flints, the majority of those in the lowest layer being entire unworn Chalk-flints, while those in the higher part are angular pieces of broken flints, with some quartz pebbles and fragments of ironstone. In some districts there is also a large percentage of sand in the clay. The whole deposit lies irregularly on the Chalk, from which the unworn flints have been derived, and by the solution of which it has been let down into hollows, funnels, and pipes. This clay is often overlain by, and sometimes it seems to pass laterally into, thick deposits of loam, brick-earth, sand, and gravel, all of which may have been derived from the destruction of the Eocene Beds.¹⁸

Plateau Gravels.—This name has been given to various unstratified gravels in the southern, eastern, and midland parts of England, because they occur on the plateaus out of which the modern river-valleys have been excavated. In Norfolk and Suffolk they generally rest on the Chalky Boulder-clay, and consist mainly of large rolled and battered flints whence they have been called "Cannon-shot Gravels."

In the Midlands they rest on Jurassic rocks and contain a mixed collection of stones, most of which have been derived from more or less distant sources. Thus around Oxford the Plateau drift contains quartzite-pebbles from the Bunter, Carboniferous

sandstones and cherts, Liassic stones, Red Chalk, and various igneous rocks. The assemblage is in fact that found in the Glacial deposits to the north, and Mr. Pocock is of opinion that the gravel is of Glacial age and is in part a decalcified Glacial deposit.¹⁹ He admits, however, that at lower levels, 130 to 200 feet above the rivers, it is sometimes rudely terraced as if it had been redistributed by fluvial action.

In Berkshire and East Oxfordshire the constituents are chiefly subangular flints and materials derived from the Eocene Beds such as flint-pebbles, quartz-pebbles, sarsen-stone, and ironstone. Mr. Osborne White also regards the gravel as of Glacial age, but as belonging to more than one Glacial epoch, and he remarks that "the Plateau and Valley gravels are very often inseparable; their more level spreads appear to be but the higher and lower members of a single graduated series, the steps and half-landings of a ruined stairway that was never complete."²⁰

River Gravels.—The manner in which disconnected tracts and terraces of gravel, sand, and loam have been formed and left at various levels in a river-valley is explained in all text-books of Physical Geology. They represent different stages in the excavation of a valley, those at the highest level above the existing stream being of course the oldest, and the others newer in proportion as they are nearer to the level of the modern alluvium.

The deposits in the valley of the Thames may be taken as an example of such accumulations. In the higher parts of the valley tracts of gravel are found at various heights, now on one side of the river, now on the other; three stages or terraces can often be distinguished, the highest being about 40 feet above the level of the river. From this highest terrace few bones have been obtained, but at the lower levels land and river shells, with remains of *Elephas primigenius*, *Elephas antiquus*, *Rhinoceros tichorhinus*, *Bison priscus*, *Rangifer tarandus*, *Equus caballus*, *Canis lupus*, and *Ursus arctos* are frequently found. Between Windsor and London the outspreads of gravel become wider and more continuous, but the surface of the older parts still rises to 30, and even 45 feet above the river, and the shells are still of fluvial species. Hence we may conclude that when these gravels were deposited the Thames had a much longer course than it has at present, and that this part of the valley was then far inland, otherwise the beds would be at a lower level and the shells would be estuarine.

Below London, at Ilford, Grays, Crayford, and Erith, there are a series of gravels, sands, and loams which rise to 25 or 30 feet above the river, but are nearly 60 feet above the base of the alluvium at Erith. These beds have yielded the mammalian remains

mentioned above, and it is only at these places that *Rhinoceros leptorhinus* and *R. tichorhinus* have been found together.²¹ The presence of *Rhinoceros megarhinus* (a Pliocene form) and the absence of the reindeer (*Rangifer tarandus*) are regarded as indications of the antiquity of the deposits. Between fifty and sixty species of land and freshwater shells have been found, several of which no longer live in Britain, e.g. *Cyrena* (*Corbicula*) *fluminalis*, *Unio littoralis*, *Pisidium amnicum*, *Hydrobia marginata*, and *Helix fruticum*. A worked flake proving the presence of Man has also been found in the lower brick-earth. Many flint implements of Palæolithic types have also been found in high-level gravels at Acton and Stoke Newington on the north side of London.

The district now drained by the river Cam contains an interesting series of river deposits which bear testimony to the successive changes that have taken place in the drainage system of this area.²² The oldest line of gravels has no connection with the modern river-valley, but crosses it nearly at right angles near Cambridge. Patches of gravel in the hill-valleys near Balsham testify to the action of streams where none now exist, and these seem to have united to form a river which ran by Wilbraham, Quy, Cambridge, Girton, Oakington, Long Stanton, and Willingham. The deposits it has left now form long gravel-capped ridges, the base of the gravels where intersected by the Cam being about 40, and their surface sometimes 60 feet above the modern alluvium. These fluviatile gravels appear to terminate abruptly near the fens of the Bedford Level, but were probably originally continuous with the gravels at Chatteris, Doddington, and March, which form similar ridges rising above the general level of the fens which surround them, and evidently mark the estuarine channel of a river which traversed the country when it stood at a somewhat lower level, and before the Fen-land existed. The shells found at March are chiefly marine, but include *Corbicula fluminalis*.

Of deposits which bear a definite relation to the modern river Cam, remains of three terraces can be recognised. The highest of them runs by Trumpington and Barnwell, about 25 feet above the alluvium, and has yielded a number of mammalian bones and teeth, with a still larger number of shells, among which *Corbicula fluminalis*, *Unio littoralis*, and *Hydrobia marginata* occur. These three shells do not occur in the lower terraces, which are respectively about 15 and 8 feet above the alluvium near Cambridge.

Lacustrine Deposits.—Two notable instances of such deposits occur in the east of England. That of Hoxne, near Diss in Suffolk, is perhaps the best known, pits at that place exposing over 30 feet of lacustrine beds without reaching the bottom; the lower beds are

marls containing bones of mammalia, freshwater shells, and remains of plants; these are overlain by brownish clay or brick-earth enclosing flint implements of a Palæolithic type. The plants include leaves of *Salix polaris*, *S. myrtinites*, and *Betula nana* (all Arctic forms), with others of more southern character, but the flora somewhat resembles that of modern Iceland.²³

Similar deposits occur in a broad depression south of Hitchin in Herts, and consist of alluvial marls and silts resting on boulder-clay and overlain by brick-earth with implements of Mesolithic type.²⁴ The flora, however, does not include the Arctic species, and indicates a more temperate climate.

Cave Deposits.—The origin of caves and the formation of the deposits found in them is explained in most books on Physical Geology. Many such caves have now been explored in England and Wales; some of them have served as dens for bears or for

Fig. 210.—SECTION ACROSS THE TRUMPINGTON GRAVELS. Distance 2 miles.

a. Lowest terrace.	d. Chalk marl.
b. Second terrace.	e. Gault.
c. Highest terrace.	f. Alluvium.

hyænas, and the bones of other animals belong to carcases which have been dragged in by these creatures. At other times they have served as shelters for man, whose occupation of them is proved by the frequent occurrence of stone implements—Palæolithic in the lower beds, and sometimes Neolithic in the higher. The caves of Creswell Crags in the Magnesian limestone on the borders of Derby and Notts afford good examples of such deposits.²⁵ In Robin Hood Cave the beds found were :—

	Feet.
5. Stalagmite united to the roof	1 to 2
4. Breccia with bones and implements	0 to 3
3. Cave earth with bones and implements	2 to 4
2. Red clayey sand with bones	2 to 4
1. Light-coloured sand with blocks of limestone fallen from the roof	2

The lowest sand yielded no organic remains, but the red sand contained bones of many animals, all of them scored with the teeth-

marks of the creatures which had dragged them into the cave, and that these were hyænas is proved by the abundance of hyæna bones and teeth belonging to individuals of all ages from cubhood upwards. Flint implements are rare in the sand, but abound in the overlying cave earth, some consisting of flint and others of quartzite, but all of Palæolithic form; bones of the same animals occur in this layer. Lastly, in the breccia above are flint and bone implements of the Neolithic type.

Some caves in the Vale of Clwyd (North Wales) have been explored by the late Dr. Hicks, and are important from their position in relation to the local Glacial deposits.²⁶ They are known as the Ffynnon Beuno and Cae Gwyn caves, and are situate in a small valley or ravine on the east side of the Vale at a level of nearly 400 feet above the sea. The valley has apparently been filled with Glacial drift of the low-level Lancashire type (see p. 629), and one of the entrances to the Cae Gwyn cave was found to be buried beneath a bank of stratified sand, gravel, and boulder-clay, the lower layers of which entered the cave and overlay the bone-bearing cave-earth. The section at this entrance was as follows:—

	Feet.	Ins.
Reddish boulder-clay with sandy seams	6	4
Sand with boulders and seams of clay	3	9
Gravelly sand with fine laminated sand below	3	5
Red laminated clay	1	0
Cave earth with bones and flint implements	2 to 5	

Dr. Hicks inferred that the contents of the cave were pre-Glacial, but this was not proved by the evidence, and the assemblage of mammalia is that of the later Palæolithic time, the commonest species being *Rhinoceros tichorhinus*, *Elephas primigenius* (the mammoth), and *Rangifer tarandus* (reindeer). They must, therefore, be regarded as inter-glacial, but anterior to the submergence which enabled the northern ice to travel so far southward.

Another important cavern is that known as Kent's Cavern, near Torquay in Devon. This was explored by Mr. Pengelly with assistance from the British Association, and classified collections of its contents may be seen in the museums at Torquay, South Kensington, and Oxford. Where the succession was complete it read as follows:—

5. Black mould.
4. Granular stalagmite (5 feet) with some bones.
3. Cave earth with many bones and Palæolithic implements.
2. Hard crystalline stalagmite (6 to 10 feet) with bones of bears.
1. Breccia with bones of bears and rude stone implements.

The cave seems to have been first occupied by bears and

occasionally by men of early Palæolithic race. In the cave earth (No. 3) hyæna bones are the most abundant, but remains of twenty-five other mammals were found, including *Elephas primigenius*, *Rhinoceros tichorhinus*, and *Rangifer tarandus*. With these were associated flint implements of two recognised Mesolithic types and a few tools made of bone. This deposit evidently represents a long period of time, and is covered by the upper stalagmite containing remains of hyæna, mammoth, fox, and horse.

Raised Beaches.—Raised beaches and sea-margins occur along many parts of the British coast-line. The beaches consist of sand and gravel, irregularly stratified, and often containing drifted shells, such as may be found on modern shores. Deposits of this kind occur at Brighton and westward along the southern part of Sussex as far as Portsdown Hill, the highest level at which they are found being about 130 feet above the sea. Inland they are banked against an old line of cliffs, the position of which is shown in Fig. 173. Raised beaches exist also at Portland Bill, where the highest part of the deposit is 50 feet above sea-level, and at many places round the coasts of Devon and Cornwall.²⁷ All these are probably contemporaneous with the raised beaches of South Wales (see p. 632), which are older than the local Glacial deposits, and in fact of meso-Glacial age.

On the Scottish coasts raised beaches and lines of cliff are found at various successive levels between 25 and 100 feet above high-water mark, four or five sometimes occurring one above another. These are of more recent age, the highest being contemporaneous with latest moraines.

Alluvial Levels.—These are marshy flats formed of the deposits left by the flood-waters of a river; they border the actual channel of the river and widen out in the lower part of its valley, till near the river's mouth they often form wide levels or marshes, which are partly of fluvial and partly of marine origin. The depth of alluvial matter which occupies the ancient valleys of our rivers near their mouths is sometimes very great; thus at Sheerness, and also at Upchurch, near Sheppey Island, borings have proved 77 feet of such alluvium. In the Essex marshes there is sometimes 50 feet of alluvial matter. At Yarmouth there is said to be 170 feet, and in the valleys of the Yare and Wensum there appears to be sometimes 60 or 70 feet of alluvium between the present surface and the chalk which lies at the bottom of the valley.

Besides the deposits above mentioned which lie within river-valleys, there are other tracts round our shores which have once been bays and inlets of the sea, and are now filled principally with marine silts and clays, though layers of peat with trunks of

trees are frequently intercalated with the silts, and mark pauses in the process of silting up. Many such tracts pass beneath the present beaches, and were evidently once much more extensive than they are now. Such are the marshes near Fleetwood, in Lancashire, the Bridgewater Levels in Somerset which pass beneath the Bristol Channel and must formerly have extended far down this estuary, the Pevensey Levels in Sussex, the Romney marshes in Kent, the Fens of Cambridge and Lincoln, and the marshes of the East Lincolnshire coast.

3. *Continental Deposits*

The cave earths and river deposits of France and other continental countries do not differ in any essential respect from those above described, and the French classification of them according to types of flint implements has already been mentioned (p. 638). Here, therefore, it is only necessary to describe such deposits as differ from anything existing in Britain. Of these the two chief are (1) the Loess, (2) the post-Glacial deposits of the Baltic area.

The Loess.—This deposit is found in the north-east of France, and in the valley of the Rhine as far south as Basle, over parts of Southern Germany, the lower parts of Bohemia, Moravia, Hungary, and Galicia, up into the Carpathian Mountains, and also through Poland and Silesia over the plains of Southern Russia. Though thickest in the valleys, it also extends onto the slopes of the hills and reaches up to levels of 2000 and even 3000 feet, but is there mingled with local detritus.

Loess is a fine yellowish or brownish argillaceous material, similar to some of the yellow loams which occur in fluvial deposits, but it is unstratified and has a marked tendency to break along vertical planes and thus to form vertical walls. It is always more or less calcareous, and often contains calcareous concretions, but the upper part is generally decalcified. It appears to be a terrestrial deposit, for the fossils it contains are almost entirely land-shells and mammalian bones; freshwater shells being of rare occurrence. The commonest shells are *Helix* (*Hygromia*) *hispida*, *Succinea oblonga*, and *Pupa muscorum*.

Diverse views have been held with regard to the origin and the age of the loess; some have thought that it resulted from the blocking of the great rivers flowing from Central Europe, their waters being ponded back by the northern ice-sheet and large lakes thus formed. Others with more reason regard it as an æolian deposit formed during an epoch of dry cold; that it was, in fact, an accumulation of dust carried by the wind and deposited on grassy steppes like those of Southern Siberia. This has been

confirmed by the discovery of a steppe-fauna in the loess at Thiede in Brunswick and at Westeregeln in Prussia. This assemblage includes some northern forms, such as *Elephas primigenius*, *Cervus tarandus*, and *Ovibos moschatus*, associated with species that now live on the Siberian tundras such as *Saiga tartarica*, *Myodes torquatus* (a Lemming), *Arctomys bobac* (a Marmot), *Lagomys pusillus* (the tailless hare), *Alactatus jaculus* (a Jerboa), and several species of *Spermophilus*.

With regard to age it has been considered to be entirely post-Glacial or late Glacial, but the evidence tends to favour the view that its formation extended over a long period of time, that its lower parts are what may be termed meso-Glacial and contain flint implements of Mesolithic types, while its higher parts are late Glacial and locally post-Glacial.

Deposits of the Baltic Region.—During the final retreat of the Scandinavian ice-sheet, the sea gradually reoccupied the trough of the Baltic, together with parts of Southern Sweden, a large part of Finland, and a small part of Russia between the Gulf of Finland and the White Sea. The Swedish geologists Munthe and de Geer assume that this was due to a concomitant subsidence, but it is quite as likely that the ice-sheet had occupied the place of the sea, which simply returned into the area as the ice retired.

The deposits of this sea are laminated clays containing *Yoldia arctica*, *Y. hyperborea*, *Pecten islandicus*, *Sipho togatus*, *Trophon truncatus*, *Natica affinis*, and other boreal forms which are only now found in the Arctic Ocean; hence they have been called the deposits of the Yoldia Sea. They do not occur in Germany, but are found in the south of Sweden, and thicken northwards till they attain a thickness of over 800 feet in Angermanland, so the conditions must have lasted a considerable time.

This geographical phase was brought to an end by an uplift of the region which not only raised the area north of Lake Onega, but also united Sweden to Denmark and converted the Baltic basin into an enclosed sea which quickly became a freshwater lake. This has been called the "Ancylus Lake" because *Ancylus fluviatilis* is a common fossil in its deposits, associated with *Limnaea ovata*, *Planorbis contortus*, *Bithinia tentaculata*, and other freshwater shells; these deposits rest unconformably on the Yoldia Beds.

This phase was terminated by a subsidence which was greater on the western than on the eastern side, allowing the waters of the North Sea to flow freely into the Baltic area, so that the freshwater lake was quickly converted into a gulf of the sea. Moreover the opening must have been wider than it is at the

present time, for the gulf was completely filled with salt water, and from the abundance of *Littorina littorea* and *L. rudis* in the grey clays left by these waters it has been called the Littorina Sea. The present conditions of brackish water with a limited and stunted fauna have been produced by a second elevation of the area.

The Ancylus Lake did not extend so far west as Christiania, where the succession of shelly clays has been described by Sars, Kjerulf, Öyen, and Brogger²⁸; the last-named recognising the following series:—

Post	{	6. Scrobicularia Clays with <i>S. piperata</i> .
Glacial		5. Tapes Beds with <i>T. pullastra</i> .
	{	4. Cardium and Ostrea Beds with <i>C. edule</i> .
		3. Mya Beds with <i>Mya truncata</i> , <i>Mytilus edulis</i> , <i>Cyprina islandica</i> , <i>Tellina baltica</i> , etc.
Late	{	2. Arca Clays with <i>Arca glacialis</i> and <i>Yoldia lenticula</i> .
Glacial		1. Yoldia Clays with <i>Y. arctica</i> , <i>Leda pernula</i> , etc.

Of these numbers 1 and 2 were formed during subsidence and correspond with the Yoldia Clays of Sweden. The Mya Beds were formed during the subsequent elevation and occur at a little over 200 metres above the sea (660 feet). The newer deposits range from 80 metres (260 feet) to sea-level, and the land appears to have been rising all the time.

F. SOME PHASES OF PLEISTOCENE GEOGRAPHY

The history of the Glacial epoch has yet to be written, for geologists are not yet agreed as to the interpretation of the records on which such a history must be based, or as to the causes which produced such a great change in the climate of Europe.

So far as we know there are only three sets of causes which could have wrought such a change of climate; these are (1) cosmical causes affecting the whole globe; (2) geographical changes involving the connection or disconnection of continents, and the consequent divergence or introduction of marine currents; (3) alterations in the arrangement of the areas of high and low barometric pressure, affecting the direction of prevalent winds.

The cosmical causes have been advocated by the late James Croll, who published a book on the *Cause of the Ice-age* in 1891, but his views have been controverted by Professor Newcombe and Mr. E. P. Culverwell. The possible geographical causes were discussed by Lyell, who argued that the elevation of land in the Arctic regions would tend to refrigerate the northern hemisphere, and that if continuous land existed between Labrador and the British Isles the climate of Northern Europe would probably become colder. Others again have suggested geographical changes

which would alter the course of the Gulf Stream, but all these ideas are unproved hypotheses.

The alteration of meteorological conditions as a cause of climatal change has recently been discussed by Mr. F. W. Harner,²⁹ who points out that the winds are an important factor in determining the distribution of climatal zones, and that existing deviations of the monthly or yearly isotherms from the normal are coincident generally with the direction of the prevalent winds. "The winds blow in a direction more or less parallel to the isobars; the latter group themselves round centres of high and low pressure. . . . Anomalous weather is due to some unusual arrangement of these areas; similarly former cases of anomalous climate can only have occurred when meteorological conditions were favourable.

"During the Glacial period the regions covered by ice might have been, to a greater or less extent, anticyclonic at all seasons, low-pressure systems prevailing at the same time over the warmer regions immediately to the south of them and over the adjoining oceans. The relative positions of areas of high and low barometric pressure, the direction of the prevalent winds, and the consequent distribution of climatic zones would in such a case have differed from those of the present time."

The prevalence of south-westerly winds over the British area at the present time is due to the fact that the centres of cyclonic storms generally pass from the Atlantic to the north or north-west of our islands. Under the conditions above imagined they would pass farther to the south, bringing oceanic winds over the Sahara and the Mediterranean Sea, while easterly winds would prevail over Britain. It has already been mentioned that the shell-banks of the Suffolk and Norfolk Crags afford actual evidence of such easterly winds during the later part of the Pliocene period. Further, as Mr. Harner points out, "the diversion of the prevalent winds of the northern part of the north Atlantic from a south-westerly to a south-easterly direction would have tended to divert the Gulf Stream, or what remained of it, towards the American coast." This abstraction of the Gulf Stream would have an enormous effect on the climate of Western Europe, equivalent, according to Dr. Croll, to a lowering of the mean annual temperature of London by 40° F.

With regard to the actual difference in the climate of Northern Europe at the time of the greatest extension of the ice, Mr. C. Reid has estimated that the average temperature of the air along the southern margin of the ice-sheet was not higher than freezing point, and that the mean annual isotherm of 38° F. must then have passed through the south of England and across Central

Europe in an oblique direction to the northern shores of the Black Sea; in other words that the mean annual temperature was 20° lower than it is now along this line.³⁰ He adds that "the Arctic plants and animals found fossil in Britain point to a similar conclusion, for the same species now flourish in a climate fully 20° colder than that of the lowlands of Britain."

Of the geographical changes which took place during the Pleistocene period within the European area some have been indicated in the preceding pages, but a brief summary of the probable sequence of events may here be given, the reader being warned that I only express the views of those who seek to avoid extremes and to reconcile the different inferences which have been drawn from the facts.

At the beginning of the period, *i.e.* at the close of Pliocene time, the British Isles were broadly united to the continent across the English Channel and across the southern part of the North Sea to Holland and Belgium. The Rhine discharged itself into the North Sea Gulf near the coast of Norfolk, and the height of Eastern England above sea-level was about the same as at present. The western parts of the British region were, however, at a much higher level than they are now, and Ireland may have been broadly united to Scotland and England, though possibly a deep narrow estuary, receiving a river from the north, lay between Ireland and Wales.

The first formation of glaciers in Ireland, Scotland, and Wales may not have been accompanied by any terrestrial movement, and the same may have been the case in Scandinavia. But of this early glacial episode few traces remain, for most of the glacial products of it would have been swept away by the subsequent advance of the ice.

There is good reason to believe that the great extension of the ice and the consequent formation of ice-sheets coincided with a general subsidence of Northern Europe, which enabled the ice to spread much farther south than it otherwise would have done, and to rise over the land in such a manner as to carry material from lower to higher levels. The extent of this submergence in Britain is at present uncertain, but it seems to have been greater in the north, where the ice was thickest, and less in the south where the ice-sheets terminated. Thus as stated on p. 615, Scotland seems to have been about 600 feet lower than at present, while in the south of England the difference was not more than 150 or 160 feet.

But although we may infer a subsidence of that amount in the area of the English Channel, we must not suppose that the Straits

of Dover were formed by that subsidence. England was still united to France, but by a much narrower tract of land, possibly only by an isthmus joining the Wealden area to the Boulonnais, the invasion of the low-lying country being protected by the continuation of the South Downs across the Channel from near Beachy Head to the French coast north of the mouth of the Somme, and by the North Downs between Dover and Calais.

For an account of the subsequent elevation of the British Isles and of the final subsidence by which Ireland was separated from England and the latter from France, the reader is referred to the author's *Building of the British Isles* (3rd ed.). The later geographical changes in the Baltic region have already been mentioned, and the history of the Neolithic time belongs rather to the antiquary than to the geologist. For a good account of what was known up to 1880 the reader is referred to Professor B. Dawkins's book on *Early Man in Britain*.

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