GEOLOGY

PRESTWICH


ARCTIC OCEAN
ATLANTIC OCEAN
NORTH SEA
BRITISH ISLANDS
WHITE SEA
GULF OF BOTHNIA
BAY OF BISCAY
MEDITERRANEAN
BLACK SEA
CASPIAN SEA
AFRICA
GEOLOGICAL
MAP OF
EUROPE
Executed under the direction of
JOSEPH PRESTWICH, F.R.S.
BY
William Topley, F.G.S., and J. G. Goodchild, F.G.S.
FROM THE LATEST SURVEYS

GEOLOGY

CHEMICAL, PHYSICAL, AND STRATIGRAPHICAL

PRESTWICH

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GEOLOGY

CHEMICAL, PHYSICAL, AND STRATIGRAPHICAL

BY

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IN TWO VOLUMES

VOL. II

STRATIGRAPHICAL AND PHYSICAL

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MDCCCLXXXVIII

PRELIMINARY REMARKS.

THE subjects discussed in the First Volume of this work related to the composition of rocks, and to the changes brought about in them by the action of the various meteorological agencies on the surface, and by thermal and chemical action at depths. In it also were described the nature of the disturbances which the rocks have undergone by the action of subterranean agencies,—the deformation of the Earth's Crust which has resulted therefrom,—the elevation of mountain-chains,—and the manner of volcanic action.

My object in this Volume is to enquire what possibly may have been the original condition of the Earth's Crust,—to note when Life first made its appearance upon it,—to determine the character of that Life, and to follow its development and successive modifications through all Geological Time. *Pari passu* with the Biological Evolution, the great physical changes of the surface, the constant alteration in the distribution of land and water, and the relation of these physiographical changes to the distribution of life on the land and in the waters, are briefly noticed.

This constitutes Geological History. It has been my endeavour not only to describe that history, and to show its continuity in our area, but also to follow the contemporaneous course of events in other parts of the world. The publications of the many Geological Societies and great Surveys of Europe, America, India, and Australasia have rendered this task practicable, although the amount of such material now at our disposal is so vast, that a mere sketch is all we can hope to attempt. By means, however, of the notes and references, the reader will be enabled to pursue the subjects further.

As I have before observed, geologists are for the most part agreed upon the main facts of Geology, but they differ in the interpretation of them. Consequently, while in geological works there is a general agreement in description, there is often a wide difference in the construction put upon the phenomena, and in the treatment of the theoretical questions involved.

I have met these theoretical questions in two ways. Those which are intimately connected either with the physical conditions, or with the chemical and life conditions peculiar to some particular period of geological history, I have discussed, as it were on the spot, in the Stratigraphical

Chapters relating to those events. The more abstract physical and cosmical problems I have relegated to the concluding Chapters; for, when the student has reached these, he may be supposed to have made himself acquainted with the conditions and facts on which they are based, and should then be better able to draw his own conclusions. In these questions also I have confined myself to the geological side of the problem, and would remind the student that any abstract enquiry should give results in accordance with geological facts. Much valuable time and research have been lost by inattention to or ignorance of the essential geological data in the investigation of such problems.

In the Illustrations I have taken, firstly, the several *Classes* and *Orders* of the Invertebrata which are peculiar to the greater Geological Periods or Divisions, and in the Plates have given figures of some characteristic Genera of each group. These Plates, which will be found at the end of each of the greater Divisions, will enable the reader to see at once to which of them he should refer his collections; while in the text he will find the figures of the more important *Species* characterising the several lesser Divisions or Formations. The figures of the Vertebrata are confined to the text.

The important part played by Corals as rock-builders has long been known and insisted upon; but of the importance of the more obscure and minute forms of life, the Sponges and Foraminifera, in building-up some of the Sedimentary Strata we now have a better knowledge than heretofore; their forms and structure having been elucidated by the researches of many palæontologists; and this has led me to give them greater prominence than usual. In the same way the great advances made in our knowledge of the Flora of the Mesozoic and Kainozoic Periods enable me to illustrate this subject more fully. For although the leaves of plants alone may be considered by Botanists to be insufficient guides to an exact determination of the plant, still they afford important information, if not always as to specific distinctions, nevertheless of much geological value in showing the prevalence of certain families and orders, and their succession in geological history.

As these subjects contribute to make the whole scheme of the Past Life on the Globe more complete, I have included in the illustrations as large a variety of the more abundant orders and genera of the Animal and Vegetable Kingdoms of the several Geological Periods as the nature of this work will allow, so that the student may have as many examples as possible of the Forms of Life in Past Times; while to see their relation to one another and their place in existing Nature he has only to refer, as a preliminary step, to the lists in Chapter v, Vol. I.

Besides the range of genera and species through time, it is desirable to know their range through space. With this object I have given, though necessarily very briefly, lists of the principal Genera occurring in synchronous or equivalent strata in the several great geological divisions of other parts of the world besides Britain. The Tables II to VI give these divisions, together with groups of their chief Fossils.

In order to follow the descriptive portions of the work relating to foreign geology, it was essential to have a Geological Map of Europe. On submitting my views to Mr. Wm. Topley, he very kindly undertook to carry them out in conjunction with Mr. T. G. Goodchild, one of his colleagues on the Geological Survey of Great Britain. My part has been confined merely to the general plan and the introduction of the Volcanoes. The reduction of the Map from the several Home and Foreign Surveys has been entirely the work of the above-named gentlemen, assisted by Mr. Herbert Goodchild[1]. I have only to express my entire satisfaction with the Map,—a satisfaction which may, I trust, be shared by my readers. The topographical details are the work of Messrs. W. and A. Keith Johnston, of Edinburgh.

The colours adopted resemble for the most part those proposed by the International Geological Congress, with the exception of the Trias, Permian, and Siluro-Cambrian, for which we have retained the tints more familiar to English Geologists.

I have now to express my thanks to the many friends who have assisted me in various ways during the progress of the work. To Professor Rupert Jones I am indebted for valuable assistance in revision of proofs, and for information respecting the distribution of the Entomostraca and Foraminifera and for the right selection of species; to my old friend, Dr. John Evans, also for kind aid with the proofs, and for the use of several of the excellent woodcuts from his work on the 'Ancient Stone Implements of Great Britain'; to the Council of the Geological Society for the use of woodcuts from the Quarterly Journal; to M. Albert Gaudry for several woodcuts from his 'Mammifères Terrestres'; to Dr. George J. Hinde for much useful information respecting Fossil Sponges, and advice in their selection; and to the Palæontographical Society, through the Rev. T. Wiltshire, for the use of various woodcuts.

I have also to express my many obligations to Dr. H. Woodward and Mr. R. Etheridge of the British Museum for much friendly help, and for permission to have drawings made of specimens in the National Collection; and to Miss Gertrude Woodward for the excellent rendering of these on the lithographed plates and in some of the woodcuts. The bulk of the woodcuts are the work of Mr. J. D. Cooper.

My thanks are also due to the Rev. Dr. Crosskey for the loan of his fine specimens of Glacial Fossils figured in Plate XVI, and for the

[1] For the list of chief authorities followed in compiling the Map, see List of Illustrations. (Maps),—p. xix.

photograph of Fig. 217. For other figures, I have to thank Dr. Archibald Geikie, the Rev. T. Wiltshire, Mr. R. H. Tiddeman, Mr. Herbert Spearing, and other friends.

I am likewise greatly indebted to the Delegates of the University Press for permission to make use of the illustrations in Professor Phillips's 'Geology of Oxford and the Thames Valley,' descriptive of the Flora, Reptiles, and other fossils of the Mesozoic Period.

I have further availed myself of the works of Professor Marsh for illustrations of the Fossil Birds and Great Reptiles of America; of those of the Marquis de Saporta and the late Professor Heer for information and illustrations of the Fossil Flora of Europe; of Mr. Starkie Gardner's Monograph on the Eocene Plants; of Lindley and Hutton's Fossil Flora for the Carboniferous Plants; of Dixon's 'Geology of Sussex,' 2nd edition, for illustrations of Chalk and Lower-Eocene Fossils; of the 'Palæontological Memoirs' of Hugh Falconer, and Professor Boyd Dawkins' 'Cave Hunting,' for the Mammalia and other objects from the Caves; of the Palæontographical Society's 'Monographs on Corals,' by Milne-Edwards and Jules Haime; on the 'Eocene Mollusca,' by F. E. Edwards and Searles Wood; and on the 'Brachiopoda,' by T. Davidson. Other illustrations I have taken from the 'Geological Survey Decades,' and the 'Memoirs' by Forbes and Bristow on the Isle of Wight, and by Ramsay on North Wales. Amongst other works which have been of similar service are Buckland's 'Bridgewater Treatise,' Salter's 'Cambridge Fossils,' Salter and Woodward's 'Chart of the Crustacea;' and in various ways others whose names are mentioned in the following pages.

Though this work has been so long in hand, I hope that I have not overlooked many of the later contributions to Geology; but they now follow each other so rapidly that it is not easy to keep up with the tide. If there be omissions, I have to apologise to the authors.

JOSEPH PRESTWICH.

November, 1887.

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LIST OF ILLUSTRATIONS.

1. MAPS.

The following list, according to Mr. Topley, includes the chief authorities followed in compiling the Map:—

United Kingdom:—The Geological Survey; and the Maps of England and Wales—Ramsay, 1878; Scotland—Geikie, 1876; Ireland—Jukes, 1867, Hull, 1878.

France:—Vasseur and Carez so far as published; the rest from Dufrénoy and Élie de Beaumont, 1841.

Belgium:—Dewalque, 1879.

Spain and Portugal (including the Pyrenees):—de Botella, 1881, in which Spain is reduced from the Geological Survey; Portugal, from a map by Ribeiro and Delgado, 1876.

Italy:—Geological Survey, 1881.

Prussia and Germany generally:—Von Dechen, 1869.

Austria-Hungary:—Von Hauer, 4 Ed., 1884.

Switzerland and the Alps are taken from the more recent maps above referred to; they are founded on the researches of Studer, Favre, and others.

Russia:—Central part from a MS. map kindly supplied by Nikitin, reduced from the Geological Survey; the Urals, by Karpinsky, 1884; the rest by de Moeller, 1878.

Sweden:—MS. map kindly supplied by Torell, reduced from the Geological Survey.

Norway:—South, by Kjerulf, 1879; North, by Dahll, 1879.

Turkey, etc.:—Toula, 1882.

Greece, the islands of Eastern Europe, and a few small areas elsewhere, are taken from Dumont's Map of Europe, 1857.

The Quaternary Beds of the North German Plain join those coloured as Tertiary in Russia. A similar difficulty, but to a smaller extent, has been felt in some other districts. Quaternary deposits thickly cover many parts of Europe, but they are not indicated if the 'solid rocks' beneath are known.

In Central Russia the line between the Trias and the Permian has been drawn by M. Nikitin; but N.W. of Perm the line is uncertain.

The 'Flysch' of Eastern Europe is included within the Tertiary area.

The Rocks coloured Carboniferous in Italy are those shown as Permo-Carboniferous on the Italian Map.

In Turkey the area coloured Carboniferous may include some Sedimentary rocks of older date.

The area coloured as Metamorphic in Norway may include some true Siluro-Cambrian rocks. In Sweden a line has been drawn by Dr. Torell, and is here engraved, dividing the Metamorphic area into two parts: the western part contains the rocks equivalent to the 'Highland Schists,' the eastern part those regarded as Archæan.

Serpentine is sometimes included in the Volcanic rocks, sometimes in the Metamorphic rocks.

The extinct Volcanic cones are given on the authority of Daubeny, Scrope, and K. Fuchs.

PLATES OF FOSSILS.

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2. WOODCUTS.

ERRATA.

Page 4, line 19 from top, *for* five *read* four.
,, 7, first column, *for* of Brie *read* de la Brie.
,, 9, line 18, in second column, *for* Kuperschieffer *read* Kupferschiefer.
,, 15, line 15, in third column, *for* cuncata *read* cuneata.
,, 25, in second footnote, *for* Calloway *read* Callaway.
,, 29, line 4 from top, *after* causes, *insert* combined with compression,
,, 33, under woodcut, *for* Bailey *read* Baily.
,, 35–38, Figs. 11, 12, 14, at end of explanations, *insert* (After Ramsay.)
,, 39, line 25 from top, *transpose* [2] *to* line 22 *at end of first sentence.*
,, ,, in second footnote, *for* Mourlo *read* Mourlon.
,, 44, lines 21 and 22 from top, delete (*p*) and (*g*).
,, 51, line 12 from top, for *Strophonema* read *Strophomena.*
,, 58, after woodcut, *for* Lindstræmi *read* Lindstrœmi.
,, 65, third line, for *venulosa* read *venulosus.*
,, 69, line 7 from top, *insert* or *before* related.
,, 71, line 22 from top, *for* II *read* III.
,, 84, first line, *for* they are *read* it is.
,, 86, line 16 from top, *for* gallic *read* galli.
,, 88, in the figure of Psilophyton the black spots should be omitted.
,, 108, line 4 from top, *for* 61 *read* 60.
,, ,, lines 8 and 9 from top, *for* 62 *read* 61.
,, 119, line 9 from top, *after* hot *insert* climates.
,, 136, under woodcut, transpose *c* and *b*; *and for* Geintiz *read* Geinitz.
,, 139, line 23 from top, for *Proterosaurus* read *Protorosaurus.*
,, 157, under Figure 69*, *for* Waterstone *read* Waterstones.
,, 179, under Figure 81, *after* Lias *insert* (After Woodward.)
,, 182 and 242, lines 13 and 8 from top, for *planicostatus* and *planicostus* read *planicosta.*
,, 192, line 15 from bottom, for *Murchisoni* read *Murchisonæ.*
,, 193 and 194, under woodcut and elsewhere, for *Latimæandrea*, etc. read *Latimæandra.*
,, 197, under woodcut, for *incisor* read *incisa.*
,, 206, in footnote, *for* Fossils and Crocodiles *read* fossil Crocodiles.
,, 210, under Figure 113, *insert* ? after *Rhynchosaurus.*
,, 220, line 20 from top, *for* range *read* district.
,, 225, under Figure 120, *for* Carpolithus *read* Carpolithes.
,, 240, in footnote, *for* Lauriol *read* Loriol.
,, 246, line 34 from top, for *athletus* read *athleta.*
,, 250, first line, *delete* UPPER.
,, ,, line 2 from top, *for* Villeneuve *read* Villenovæ.
,, ,, in Table, fifth line from bottom, for *Oolite* read *Oolithe.*
,, ,, at end of first column of Table (outside column) *insert* PART OF *before* LOWER JURASSIC.
,, 256, line 5 from bottom, for *Spirifera* read *Spiriferina.*
,, 262, lines 11 and 25 from top, for *Bennettites* read *Benettites.*
,, 265, line 14, for *I. Ma telli* read *I. Mantelli.*
,, 266, line 18 from top, for *elata* read *alata.*
,, 268, line 16 from bottom, *transfer* Sandy and Potton *to follow* Leighton *in same line.*
,, 270, line 9 from top, *for* Buckinghamshire *read* Bedfordshire.
,, ,, line 12 from bottom, *for* Gibsiana *read* Gibbsiana.

Page 271 and 272, lines 5, 20, and 24 from top, for *Deshaysii* read *Deshayesii*.
„ „ line 11 from top, for *camplylodon* read *campylodon*.
„ 271, 272, 274, and 285, for *Mathesonian* and *Mathersoni* read *Matheronianum*.
„ 282, lines 5 and 13 from top, *for* Brown *read* Browne.
„ 290, line 13 from bottom, delete *cœlenterata*;
„ 308, in second column of Table, for *semicaniculatus* read *semicanaliculatus*.
„ 352, under Figure 175, for *Merginulina* read *Marginulina*.
„ 380, line 3 from top, *for* Scheucheri *read* Scheuchzeri.
„ 381, column 3, and p. 382, first line, *for* Rupellian *read* Rupelian.
„ 382, line 21, for *Aquitainian* read *Aquitanian*.
„ 386, line 21 from top, *for* Cyprideæ *read* Cypridæ.
„ 398, line 9 from top, *for* Lithothalmium *read* Lithothamnium.
„ „ line 2 from bottom, *for* subpyrenecanus *read* subpyernaicus.
„ „ in footnote, *for* Gaudeloupe *read* Grateloupe.
„ 399, under Figure 199, *for* Gaudy *read* Gaudry.
„ 401, line 6, for *Bythinia* read *Bithynia*.
„ 406, line 21 from top, for *Aceratherium* read *Acerotherium*.
„ 410, line 17 from top, *for* Cameleopardis *read* Cameleopardalis.
„ 412, line 13 from bottom, for *littorata* read *litterata*.
„ 413, line 11 from bottom, for *cinnamoni* read *cinnamomi*.
„ 436, line 17, for *Acrotherium* read *Acerotherium*.

PART II.

CHAPTER I.

STRATIGRAPHICAL GEOLOGY.

Early Condition of the Earth's Crust. Order of Stratigraphical Succession. Variable Areas of Deposition of Sedimentary Strata. The Cause of 'Breaks' in the order of Stratigraphical Succession. Geographical Distribution of the Sedimentary Strata. Uncertain Synchronism. Tables of the Sedimentary Strata—(1) in Europe; (2) North America; (3) India; (4) Australia; (5) New Zealand; (6) South Africa.

In Stratigraphical Geology we may either commence with the more recent strata, and work backwards to the older, or we may take the strata in the reverse order, and work onwards from the most ancient to the most recent. I give the preference to the latter plan, inasmuch as it has the advantage of following geological history from antecedent phenomena; of showing in their natural order the successive changes in the earth's crust; and also of proceeding continuously with the growth and development of the fauna and flora through all the geological periods. On the other hand, the first-mentioned plan has the advantage of commencing with known and existing conditions, and going gradually back to the more obscure conditions of the past.

Early Conditions of the Earth's Crust. Stratigraphical Geology may be said to begin when the earth had cooled down sufficiently from its original fluid state to allow of the formation of a solid crust, the surface of which, becoming subject to ordinary atmospheric influences, underwent the unceasing changes of degradation and reconstruction, the principles of which have been described in Part I of this work. At the same time, the continuous contraction of the nucleus, due to secular refrigeration, produced from time to time those corrugations with elevations and depressions of different portions of the crust, which have successively altered the relative position of the land and sea, and have been the cause of the irregular distribution of sedimentary strata.

Of the crust first formed on the molten substratum we know nothing[1]. Exposed to great atmospheric pressure and subject to a very high temperature, there can be little doubt that the ordinary subaërial agencies

[1] See vol. i. p. 417, and also the last chapter in this volume.

acted with intense energy on its surface. Simultaneously the loss of heat —the rapid contraction—the frequent fracturing of a crust which must for a long period have been thin and weak—the possible submergence of portions of it in the fluid substratum—combined with the wear and tear of long ages—and the subsequent covering of Sedimentary Strata, have so removed from our sight or disguised the original crust, that we may never become acquainted with the early primordial rocks of the earth's surface.

It was not until the crust acquired greater stability that the subaërial agencies would begin to operate in the manner which we are accustomed to see—that water would lodge on the surface and sea-basins form—that lands would be subject to erosion,—and that the persistent development of the sedimentary deposits, with their long record of Life on the Earth, commenced their marvellous superstructure. The base of this great superstructure, exposed to contact with the heated interior, shows, as we have before explained, the effects of that contact in curious changes of molecular structure, and of mineral combinations, from which the upper portions are comparatively or entirely free. Wherever we are able to reach to a sufficient depth beneath the higher-lying strata, we meet with the altered deposits which constitute, with the plutonic and allied rocks, those which we now regard as the fundamental rocks of the earth.

It will be our object in this volume to follow, through unfathomable ages, the growth and succession of this great mass of Sedimentary Strata—to note their chief physical features, their contemporary life, and, briefly, their distribution over the surface of the globe. As we go back in time a more general uniformity is found to have prevailed in all latitudes, which gradually became less in subsequent ages as we approach more recent geological times, until ultimately the life in the different regions of the earth stands out in all the marked individuality of the present day.

Order of Succession. The unceasing action of rain, rivers, waves and currents, and frost, has led through all time to the formation of a succession of strata, which, though in unbroken sequence on the whole, have varied so much in their areas of deposition, that we nowhere find the series complete. There has been necessarily a break in continuity in those areas which underwent elevation and were for certain periods above the sea; but the continuity of the geological series has always been maintained in some one area or another. Contemporaneous strata can only exist in those areas which were simultaneously areas of depression, and over which the waters of the sea spread at one and the same time.

'Breaks.' Consequently there has been, over those areas which at various times formed the dry lands, an interruption of sedimentary deposition, so that there the regular sequence of the stratified strata is broken. This interruption forms what is termed a 'break' in the stratigraphical succession, and constitutes also a 'break' or gap in the geological record. But although, in consequence of this, certain formations are wanting in every country, the order of those which are present is always the same. Any of them may be absent, but those present invariably succeed one another in the same relative order. In the annexed diagram the important breaks which, in Europe, exist between the several great divisions of the geological series are roughly represented (see also vol. i. p. 45).

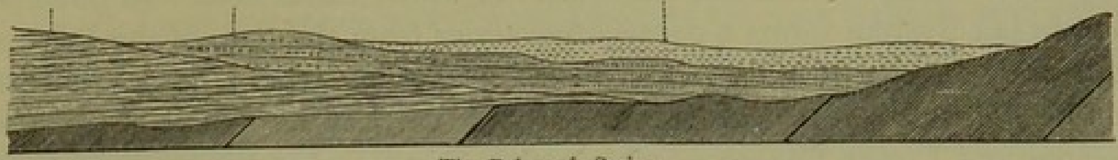

FIG. 1. *Diagram illustrative of three great 'Breaks' in stratigraphical succession.*

These breaks of continuity in stratigraphical and palæontological succession have afforded convenient lines of division whereby to group the whole of the sedimentary strata; smaller breaks having only a local importance, whereas the larger gaps are of great geographical extent. That these divisional lines are to a certain extent arbitrary will be evident from what we have just said; the gaps in the sequence existing in one part of the world being filled up in another region, where the gaps occur at different geological times. The major 'breaks,' which are of wide application, have served to group the whole of the sedimentary deposits into four great divisions or periods of time. The oldest of these is called the Archæan; the next the Palæozoic; then the Secondary, or Mesozoic; and the uppermost, the Tertiary or Cainozoic. To these has been added a fifth, or Quaternary, period; but this is of relatively very small duration and, not having been preceded by any important break, may rather be considered as a sub-division of the Tertiary. Secondary 'breaks' have further served to divide the successive Periods into fourteen Epochs, which are again subdivided into a number of Formations more or less local (Table I. p. 6).

The great time-divisions are of almost universal application; but the smaller 'breaks in continuity,' which are of frequent occurrence in all areas, are subject to constant differences of extent and value; consequently, in filling up the details of the several geographical areas, each one is found to have its own local stamp, and possesses its own special terms, some knowledge of which is as essential to the geologist as is the language of a country to the traveller, if he would pass through it with profit.

At the end of this chapter are Tables of the several local groups of strata, with their synonyms, in some of the more important regions of the world. The fundamental Archæan rocks, with which we commence, are everywhere very much alike. When, however, we proceed to study the strata which follow on these fundamental rocks, marked differences appear in their relative petrological characters and importance,—in the exact synchronism of their divisions,—and in the proportion and specific character of their organic remains, though the generic characters show a remarkable uniformity.

In Western North-America the great break, so conspicuous in Europe between the Cretaceous and Tertiary series, does not exist, and there are passage-beds having characters of the two periods in common. In a similar way the Carboniferous strata in America pass gradually upwards into the Permian without the unconformity which exists here. In India the Gondwána System forms a consecutive series from the base of the Permian to the top of the Jurassic strata. In New Zealand, again, no marked line can be drawn between the Cretaceous and Tertiary series, the Upper Cretaceous and Lower Eocene forming an unbroken and continuous series.

The extent and distribution of the main stratigraphical divisions throughout the world are sketched in the frontispiece map of vol. i, while the chief minor sub-divisions over the more limited European area are given in the map which forms the frontispiece to this volume.

The following Tables show the equivalent strata in various parts of Europe, and in America, Asia, Australasia, and Africa. In the five latter, besides the local terms, short lists of the characteristic genera of the fauna and flora are attached for the purpose of showing the distribution of some of the more important life-forms over the globe at the several contemporaneous epochs. It must not, however, be supposed, in correlating distant formations with those of Europe, or even the European formations amongst themselves, that the parallelism at present adopted is exactly conformable with synchronism in time. It represents rather the homotaxial relations of the groups. They may be, or may not be, the exact equivalents in time, though they are so, no doubt, approximately. In fact, unless we suppose, as Edward Forbes suggested, that species may have originated in different centres, it would seem more probable that identity of species between Formations in distant areas would imply, not synchronism, but such a difference of age as would allow for the species to have travelled over the intermediate distances. Thus the flora of the Upper Coal-Measures of Australia consists of Cycads closely related to those of the Mesozoic flora of Europe, while the fauna is distinctly Palæozoic; and had we no other evidence, it would be difficult to say whether the Cycadaceous flora originated during Carboniferous times in the Eastern hemisphere, and only reached Europe towards the end of the Permian, or whether the Carboniferous flora of Europe only reached Australia during the later times. These stratigraphical divisions may therefore hereafter require correction.

As many of the species characteristic of the several Formations in England, given in the successive Stratigraphical chapters, equally characterise the same Formations throughout Europe, I have not deemed it necessary to give lists of them in Table I.[1] In the Tables of the Indian, American, Australasian, and African Formations, where the species are mostly different, and the space at our disposal will not allow of descriptive lists in the text, short lists of some of the characteristic *genera* are attached. In those more distant regions it is not possible to correlate the strata by identity of *species*.

Nevertheless, although few, there are a certain number of species in common throughout all those regions at most of the geological periods: while the large community of genera amongst the Invertebrata everywhere is remarkable. This community exists from the earliest times. The same genera of Mollusca and other invertebrate forms appear with the dawn of geological history all over the world. Not only so, but, although many genera die out, a certain proportion of those which appear in the Cambrian period, together with the larger proportion of those which come in at a later period, survive to recent times; and while the species have in all times been largely affected by surrounding conditions[2], the genera have maintained their relationship throughout, and continued their course unscathed through long periods and under every variety of conditions. With all the differentiation which has gone on in the species, comparatively little change has taken place in the genera. The main stems continue unaltered, while the offshoots have been aberrant forms which flourished for a time and then died out in their respective provinces.

In the higher forms of life, however, new families, new orders, and new classes successively appear, of which a large number die out and disappear entirely, while others survive, with modifications, to recent times. The way in which these changes have been effected constitutes one of the great problems of the day. From whichever side it may be argued, this uniformity and persistence of certain forms of life, this striking in of new, and the abrupt termination and extinction of other forms, are demonstrable palæontological phenomena which must, equally with the more special details of recent life, be fully considered by the student in investigating the important questions connected with Evolution.

The species which have this world-wide range are given in Roman characters in the following Tables, the genera being in italics. The minor stratigraphical divisions are omitted. They will be found in the text. The French series refer chiefly to the strata in the Paris Basin. The Swiss series include the Jura, the Alps, and parts of Northern Italy.

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[1] The student should consult the lists given by Professor Renevier in his 'Tableau des Terrains Sédimentaires.'

[2] This is not the place to enter upon these special questions, but, amongst others, on the point named above the interesting work on 'Island Life,' by Mr. Wallace, should be consulted.

TABLE I.—Table of the Sedimentary Strata in England Continental

			England.	Belgium.
Recent.			*Alluvial and Peat Beds, Dunes, Beaches, Shingle Banks, Shell-beds,*	
Period.	*Epoch.*	*Series.*	*Formation.*	
Quaternary.	Pleistocene.	Post-Glacial.	Loess; Raised Beaches.	Campinian Sands; Hesbayan loam.
			Valley-Gravels; Ossiferous Caves.	Valley-gravels; Ossiferous Caves.
		Glacial.	Boulder-clays, Gravels, and Sands.	*Wanting.*
			Clyde Shell-beds.	*Wanting.*
		Pre-Glacial.	Westleton Sands and Shingle, and Bure Valley Crag.	*Wanting.*
			Forest and Elephant-beds.	*Wanting.*
Tertiary or Kainozoic.	Pliocene.		Chillesford beds. Norwich and Red or Upper Crags.	Scaldisian System. (*Sables à Trophon antiquum.*)
			Lower or White (Coralline) Crag.	Anversian System. (*Sables à Isocardia cor.*)
	Miocene.		Lenham Sands?	Diestian?
			Wanting.	*Wanting.*
			Wanting.	*Wanting.*
	Oligocene.	Upper.	*Wanting.*	Bolderian System (*pars*)?
		Middle.	Lignites of Bovey Tracey? Hempstead Beds.	Rupelian System (Clays of Boom and Sands of Klein-Spauwen).
			Bembridge and Osborne Beds.	Upper Tongrian System.
		Lower.	Headon Hill and Brockenhurst Beds.	Lower Tongrian System.
	Eocene.	Upper.	Barton Clay and Sands (Upper Bagshots?).	Wemmelian, and Laekenian.
			Bracklesham Sands (Middle Bagshots).	Bruxellian and Panisellian Systems.
		Lower.	Lower Bagshot Sands.	Upper Ypresian System.
			London Clay and Basement Bed (Oldhaven, *pars*).	Lower Ypresian System.
			Woolwich and Reading Series (Oldhaven, *pars*).	Upper Landenian System.
			Thanet Sands.	Lower Landenian and Heersian Systems.
			Wanting.	Montian System.
Secondary or Mesozoic.	Cretaceous.	Upper.	*Wanting.*	Danian and Maestrichtian Systems.
			Wanting.	Tufeau of Ciply.
			Chalk with flints. Chalk without flints.	Senonian System.
			Chalk Marl. Chloritic Chalk.	Nervian System (Dumont).
			Upper Greensand, Gault and Folkestone Beds.	Hervian System (Dumont). (*Meule de Bracquegnies*).
		Lower or Neocomian.	Lower Greensand. Atherfield and Punfield Beds. Weald Clay. Hastings Sands.	Aachenian System. (*Sables et Argile d'Hautrage*).

ND THEIR CORRELATION WITH SOME OF THE PRINCIPAL
ROUPS.

FRANCE.	GERMANY.	SWITZERLAND AND NORTH ITALY.
oral Banks, Travertines, Volcanic Ejectamenta:—passim.		
Loess; Diluvium Rouge. Diluvium Gris; Ossiferous Caves and Breccias. Erratic Drifts and old Moraines of the Vosges and Pyrenees. 'Diluvium Scandinave'? Sands and Gravels of St. Prest.	Loess or Lehm. Old Gravels of the Rhine and other River valleys; Ossiferous Caves. Boulder Clay and Gravels with Erratic Blocks of North Germany. Old Alluviums.	Loess; Old Diluvium. Ossiferous Caves and Breccias. Erratic Drift and old Moraines of the Alps and Jura. Infra-glacial Alluvium of Geneva, etc.
Faluns of the Cotentin. Trachytic Breccias of Perrier. Marls of Hauterives. Drift Deposits of La Bresse.	*Wanting.* Congeria-Marls and Clays (Tegel).	Sands of Asti. Subappenine Beds. (Monte Mario, Rome; Sicily.)
Faluns of Salles. Faluns of Anjou and Rennes. Faluns of Touraine and of Léognan.	Sands of Eppelsheim. Limestone of Leitha. Clays of Holstein and Lüneburg.	Marls of Œningen. Upper Marine Molasse. Lower Freshwater Molasse.
Marls of La Limagne. Calcaire of Beauce. Sands of Étampes and Fontainebleau. Phosphorites of Quercy. Calcaire of Brie, and Gypsiferous Marls of Montmartre.	Marls and Lignites of Osnabrück. Sands of Cassel. Sands of Stettin and Weinheim. Clays and Sands of Egeln and Magdeburg. Lignites, Plant and Amber Beds of the North of Germany.	Nagelfluh. Red Molasse. Glaris slates. Fucoidal Flysch, and Nummulitic Beds of the Diablerets.
Marls and Calcaire of St. Ouen. Sands of Beauchamp.	Nummulitic Beds of Kressemberg and Hæring.	Limestones of the Pilate, Righi, and Fœhnern; Nummulitic of the Vicentin.
Calcaire Grossier and Glauconie Grossière.	Nummulitic Beds of Reichenhall.	The Nummulitic and Fucoidal Beds of Northern Italy; Monte Bolca beds.
Nummulitic Sands of the Soissonnais (Lits Coquilliers).	*Wanting.*	*Wanting.*
Argile plastique.	*Wanting.*	*Wanting.*
Lignites, and Sands of Rilly and of Bracheux.	*Wanting.*	*Wanting.*
Wanting.	*Wanting.*	*Wanting.*
Wanting.	*Wanting.*	*Wanting.*
Calcaire Pisolitique, and Calcaire à *Baculites.*	(*Chalk of Faxoe.*)	*Wanting.*
Senonian Stage. (A. D'Orbigny.) (à *Micraster cor-anguinum.*)	Upper Pläner and Quadersandstein.	Limestones of St. Julien and Annecy.
Turonian Stage. (A. D'Orbigny.) (à *Terebratula gracilis.*) (à *Belemnites plenus.*)	Middle Pläner, etc. Seewen-Mergel.	*Wanting.*
Cenomanian Stage. (A. D'Orbigny.) (à *Pecten asper.*)	Lower Pläner and Quadersandstein.	Limestones of St. Croix and Cheville. Greensands of the Perte du Rhône.
Albian Stage. ,,	Flammenmergel, and Marls of Halberstadt.	Vraconnian. Albian.
Aptian Stage. ,,		Sandstones and Limestones of the Perte du Rhône.
Urgonian Stage. Upper Neocomian. Lower Neocomian.	Clays and Conglomerate of Hils and Wealden Beds (*pars*).	Marls of Hauterive. Valangian Limestones.

TABLE I.—

Period.	*Epoch.*	*Series.*	England. *Formation.*	Belgium.
Secondary or Mesozoic.	Jurassic.	Upper Oolites.	Purbeck Beds.	*Wanting.*
			Portland Stone and Sands.	*Wanting.*
			Kimmeridge Clay.	*Wanting.*
		Middle Oolites.	Coral Rag. } Coralline Oolite.	*Wanting.*
			Calcareous Grit } Coralline Oolite.	*Wanting.*
			Oxford Clay.	*Wanting.*
			Kelloway Rock.	*Wanting.*
		Lower Oolites.	Cornbrash.	*Wanting.*
			Forest-marble.	*Wanting.*
			Bradford Clay.	*Wanting.*
			Great Oolite and Stonesfield Beds.	*Wanting.*
			Fuller's Earth.	} Oolite of Longwy.
			Inferior Oolite.	} Oolite of Longwy.
			Sands of Inferior Oolite.	Limonite of Mont St. Martin.
		Liassic.	Upper Lias.	Schist and Marls of Grandcourt.
			Middle Lias or Marlstone.	Marls of Arlon and of Aubange.
			Lower Lias.	Marls of Jamoigne.
			White Lias.	Marls of Helmsingen.
	Triassic.	Upper.	Rhætic or Penarth Beds.	Sandstones of Martinsart.
			Upper New Red Sandstone (Keuper).	Marls and Sandstones of the Semois (Keuprian System).
		Middle.	*Wanting.*	*Wanting.*
		Lower.	Lower New Red Sandstone (Bunter).	Conglomerates of Malmédy (Pœcilian System).
Palæozoic or Primary.	Permian or Dyas.	Upper.	Upper Red Sandstone and Marls.	*Wanting.*
			Magnesian Limestone and Marl-slates.	*Wanting.*
		Lower.	Lower Red Sandstone and Breccias.	*Wanting.*
	Carboniferous.	Upper.	Coal-Measures.	Terrain Houiller.
			Millstone Grit.	Sandstones and Conglomerates of Hainaut.
			Yoredale Rocks.	
		Lower.	Carboniferous or Mountain-Limestone.	Limestones of Visé and Namur.
			Lower Carboniferous Shales, etc.	Limestones of Dinant and Tournay.
	Devonian (Old Red Sandstone).	Upper.	Upper or Pilton Group.	Schists of Famenne.
		Middle.	Middle or Ilfracombe Group.	Limestone of Givet.
		Lower.	Lower or Lynton Group.	Conglomerates of Burnot.
	Silurian.	Upper.	Tilestones and Bone-bed.	*Wanting.*
			Ludlow Beds.	*Wanting.*
			Wenlock Limestones and Shales.	*Wanting.*
			Mayhill Sandstones.	*Wanting.*
		Lower.	Llandovery Beds.	
			Bala and Caradoc Beds.	Schists of Gembloux and Oisquercq.
			Llandeilo Flags.	Quartzites of Blanmont and Tubize.
			Arenig Schists.	
	Cambrian	Upper.	Tremadoc Slates.	Violet Slates of Salm-Château.
			Lingula Flags.	Black Slates of Revin and Fumay.
		Lower.	Menevian Beds.	
			Longmynd Beds.	Slates and Quartzites of Deville.
	Archæan.		Pre-Cambrian and Laurentian.	*Wanting.*

ntinued).

France.	Germany.	Switzerland and North Italy.
alcaire Purbeckien. imestones à *Trigonia gibbosa*. arls à *Exogyra virgula*. alcaire Corallien, and Oolite de Trouville. arls of Dives. alcaire Callovien.	White Jura or Malm. { Marls of Münder. Einbeckhausen Limestone. Solenhofen Beds. Limestone of Ulm. Dolomite of Geisslingen. *Zone à Ammonites Lamberti.* }	Gypseous Marls. Limestone of Soleure. Virgulien Inférieure. Coralline Oolite of Locle. Argovian Limestone. Kellovian Limestones and Marls.
alcaire de Ranville, and Upper Great Oolite of Calvados, or Calcaire à Polypiers.	Upper Division of the Brown Jura or Dogger.	Cornbrash of Movelier and Salins. Great Oolite of the Bernese and Salinois Jura.
ower Great Oolite, or Oolite of Caen. olite of Bayeux; and Mâlière.	Lower and Middle Divisions of the Brown Jura or Dogger.	Vesulian Marls. Murchisonæ-Sandstein. Opalinus-shales.
arnes Toarciennes. alcaire Liasien. alcaire Sinémurien. andstone of Hettange.	Black Jura or Lias. Dachstein-kalk.	Numismalis-shales. Marls of Balingen. Cardinien-schichten.
hætic (Infra-Lias). arnes Irisées, and Gypse. alcaire Conchylien. rès Bigarré (Grès Vosgien, *pars*), and Conglomerates.	Kössen Beds. Keuper Sandstein; Hallstatt and St. Cassian beds. Muschelkalk. Bunter Sandstein.	Aviculacontorta-Zone. Cargneule and Dolomitic Limestone of the Vaudoise Alps. Virgloria-kalk *. Upper Verrucano? * In Italy there are no strata, south of Lombardy, older than the Trias.
chists of Lodève. andstones, Breccias, Marls, and Conglomerates of the Vosges and the Autunios.	Zechstein and Kuperschieffer. Rothliegende.	*Wanting.* Red Conglomerates of Glaris and Grisons.
errain Houiller. nthraciferous Sandstones and Conglomerates. arboniferous Limestone. rauwacke Houiller?	Steinkohlen-flötze. Culm and Posidonomyen-Schiefer. Berg-kalk. Aelthre-Steinkohle.	Slates of Erbingen. Conglomerates and Schists of Trient, etc.
imestone and Dolomites of Ferques. lack Limestones of Néhou. andstone of Gahard.	Clymenien-kalk. Eifel Limestone. Schists and Grauwacke of Coblentz.	Metamorphic Schists of Gerlach?
Wanting. *Wanting.* White Limestone of Erbray and Schists of St. Sauveur. Slates of Riadan. Sandstone of May. Slates of Angers. Armorican Sandstone.	Schists of Zorg. Grauwacke of Tann, and Stages H, G, F, and E of Bohemia (Barrande). Schists of Leimbach. Stage D of Bohemia.	Represented perhaps by the Gneissic and Schistose rocks of the Central Alps? (Renevier.)
Red Schists and Conglomerates of Pontreau and Clécy. Slates of Rennes and St. Lo.	Schists of Saalfeld. Primordial zone or Stage C of Barrande.	
Gneiss of Brittany and the Beaujolais?	Stages B and A of Barrande. Schists and Gneiss of Bavaria.	Gneiss of the Jungfrau (Favre).

TABLE II.—Classified List of the Formations in India (P., Peninsular India, and adjacent Territories; E.-P., Extra-Peninsular); with some of the characteristic genera of the Flora and Fauna [1].

General Time-Divisions, or Age.	Local Groups.	Characteristic Fossil Genera.
Recent . . .	P. Indo-Gangetic Alluvium.	Shells now living in the district, and Mammalian remains of recent species.
Pleistocene and Glacial (?) .	P. Old Alluvium of Narbada and Krishna. Raised Shell-beds. Low-level Laterite.	*Melania, Bulimus, Planorbis, Corbicula. Elephas, Rhinoceros, Hippopotamus, Equus, Ursus.* Palæolithic Implements.
	E.-P. High-level Drifts with boulders, of the plains of Ráwalpindi and Pesháwar.	*Limnæus, Planorbis, Paludina, Bythinia, Bulimus, Melania, Opeas.*
Pliocene . . .	P. Cuddalore Sandstone (?). Travancore Limestones. Beds of Guzerat and Cutch. Ratnágiri Plant-beds?	Silicified Woods (Exogenous). *Bulimus, Paludina, Melania, Unio; Strombus, Cassis, Voluta; Corbula, Ostrea, Pecten.*
	E.-P. Upper Manchar of Sind. Upper Sewaliks.	*Camelopardalis, Cervus, Dinotherium, Elephas, Hipparion, Hippopotamus, Hyopotamus, Macacus, Machairodus, Mastodon, Rhinoceros, Sivatherium, Sus.*
Miocene . . .	P. Argillaceous beds of Cutch.	*Turritella, Venus, Corbula, Ostrea, Vycarya.*
	E.-P. Gáy of Sind and Lower Manchar. Lower Sewaliks.	*Breynia, Echinolampas. Ostrea, Arca, Dosinia, Rhinoceros, Amphicyon, Mastodon, Dinotherium, Hyopotamus, Anthracotherium.*
Eocene . . .	P. Nummulitic beds of Surat. High-level Laterite.	*Nummulites, Orbitoides, Alveolina. Ostrea, Rostellaria, Natica.*
	E.-P. Nummulitic Limestones of Sind and Punjab. Coal-measures of Assam. Salt region of the Kohát.	*Vulsella, Ombina* (?), *Nerita, Cerithium* (? C. giganteum, Lam.), *Ostrea,* (? O. globosa, Sby.), *Cardita, Pholadomya, Crassatella. Conoclypeus.*
Cretaceous . .	P. The Lameta Group. Intertrappean beds of Bombay, and of Nágpur.	*Titanosaurus. Physa, Paludina, Valvata. Alata, Cerithium, Fasciolaria, Trigonia; Nautilus* (N. Danicus), *Ammonites. Hemiaster, Galerites* (Echinoconus conicus).
	The Arialúr Group. The Trichinopoly and Pondicherry Group.	*Isastræa. Trochosmilia. Pholodomya, Ostrea* (O. diluviana). *Nautilus, Ammonites* (A. peramplus).
	The Utatúr and Madras Groups. The Bágh Beds.	*Siphonia* (S. pyriformis). *Isastræa, Astrocænia. Cidaris* (C. hirudo). *Terebratula* (T. depressa); *Ostrea; Pleurotomaria; Ammonites* (A. rostratus), *Turrilites.*
	E.-P. Olive Group and Boulder-shales of Punjab. The *Cardita-Beaumonti* beds. Hippurite Limestone, Sind.	*Cardita, Ostrea, Rostellaria; Nautilus. Epiaster.* Corals. Crocodilian remains. *Hippurites,* Echinoderms, Mollusca.
Lower Cretaceous or Neocomian . .	P. Neocomian beds of Cutch. E.-P. Beds in Chicháli Pass.	*Ammonites* (A. Deshayesi), *Crioceras.*

[1] Compiled from Medlicott and Blanford's 'Manual of the Geology of India.'

General Time-Divisions, or Age.	Local Groups.	Characteristic Fossil Genera.
Jurassic (*Upper Gondwána System.*)	P. Umia Group. Cutch (*Portlandian*).	*Alethopteris* (A. Whitbyensis), *Otozamites* (O. imbricatus). *Trigonia, Gryphæa, Astarte, Goniomya; Belemnites, Ammonites* (A. suprajurensis). *Plesiosaurus.*
	Katrol Group. Cutch (*Kimeridgian*).	*Sphenopteris* (S. arguta), *Otozamites, Alethopteris. Ammonites* (A. perarmatus, A. plicatilis), *Belemnites.*
	Chári Group. Cutch (*Oxfordian*).	*Terebratula* (T. sella, var., T. biplicata, var.); *Ammonites* (A. athleta, A. Lamberti, A. macrocephalus), *Ancyloceras.*
	Packham Group. Cutch (*Bathonian*).	*Corbula, Astarte, Cucullæa; Lima, Gervillia Rhynchonella* (near R. concinna).
	The Cutch, Jabalpur, and Rájmahál Groups. Mahádeva Series.	*Tæniopteris* (T. ovalis), *Sphenopteris, Phytophyllum, Otozamites, Cycadites; Echinostrobus. Estheria. Lepidotus, Dapedius, Ceratodus.*
	E.-P. Gienmal Sandstone, and Spiti Shales of the Punjab (*Upper Jurassic*).	*Anatina, Avicula* (A. echinata), *Ostrea, Cyprina, Nucula, Inoceramus, Pecten* (P. lens); *Pleurotomaria; Belemnites, Ammonites.*
Triassic (*Lower Gondwána System.*)	P. Panchet Group.	*Dicynodon, Ancistrodon. Schizoneura, Pecopteris* (P. concinna), *Cyclopteris* (C. pachyrachis). *Gonioglyptus.*
	The Damúda Series, including the Coal-fields of the Birbhúm Bandar, Ràniganj, the Barákartos, and other districts.	*Archegosaurus* (?), *Brachyops. Pterophyllum, Noeggerathiopsis, Phyllotheca, Vertebraria, Glossopteris, Alethopteris, Tæniopteris, Gangamopteris, Sagenopteris.*
	E.-P. Lower Tagling Limestone. Ceratite and other Beds of the Salt Range. Liláng Series.	*Spirifer, Athyris; Ostrea, Pecten* (P. Valoniensis); *Cardinia, Gervillia, Myaphoria; Halobia* (H. Lommeli), *Monotis, Megalodon; Chemnitzia, Dentalium; Bellerophon; Belemnites, Ammonites, Ceratites, Orthoceras.*
Permian	P. Karharbári group.	*Gangamopteris, Schizoneura, Noeggerathia, Glossozamites, Voltzia* (V. heterophylla).
	Tálchir Group, and Boulder Bed.	*Gangamopteris, Glossopteris, Noeggerathia*? Annelid tracks. Insects (one wing).
	E.-P. (*Wanting*?).	
Carboniferous	P. (*Wanting.*) E.-P. Salt Range Limestones. The Damúda series of Sikkim. Kuling Series.	*Michelinia* (M. favosa), *Lithostrontion* (L. basaltiforme). *Spirifer* (S. striatus), *Athyris* (A. Roysii), *Productus* (P. semireticulatus); *Aviculopecten; Conularia; Bellerophon; Orthoceras, Goniatites, Ceratites, Ammonites. Acrodus.*
Devonian	(*Wanting*?).	
Silurian	P. Vindhyan Series. The Bhánrer, Rewar, and Kaimur Groups. The Karnul Formation. The Bhima Group.	(No organic remains yet found.)
	E.-P. Obolus-beds of the Salt Range. Muth and Bhábeh Series.	*Obolus, Orthis, Strophomena. Tentaculites. Cyathophyllum, Syringopora, Chætetes.*
?	P. The Bijáwar Series. E.-P. The Gneissic Schists of the Himalayas.	None found.
Archæan	P. The Arvali and Bundelkhand Gneisses. E.-P. The Central Gneiss of the Himalayas.	None found.

TABLE III.—Classified List of the chief Groups of Strata in North America, with some of the characteristic Genera of the Flora and Fauna[1].

		Periods.	Local Characters, Names, and Epochs.	Characteristic Genera.
Quaternary, or Age of Man.	*Recent.*	Modern Era.	Indian Shell-mounds.	Tapir, Peccary, Bison, etc. Man.
	Pleistocene.	Terrace.	Raised Beaches and Coast Terraces. River Terraces of the Connecticut, and other rivers.	Mya truncata, Saxicava arctica, *Macoma, Astarte,* Natica clausa, Yoldia glacialis, Buccinum Grœnlandicum, Pecten Islandicus. *Beluga.*
		Champlain.	*Alluvian Deposits.* Loess of the Mississippi. Flood Deposits. *Diluvian Deposits.* Orange-sand Beds. Gravels and Erie Clays.	Elephas primigenius[2], *Mastodon Americanus, Bos, Bison, Tapirus, Megatherium, Mylodon, Megalonyx, Felis, Ursus, Equus, Castoroides,* Cervus Tarandus, *Ovibos.* *Paludina, Melania, Cyclas, Physa, Cyclostoma, Limnæus, Planorbis.*
		Glacial.	Erratic Blocks. Boulder-clay and Drift.	Débris of plants and trees.
Tertiary, or Mammalian Age.	*Pliocene.*	Sumter.	Loams, Sands and Phosphatic Beds of North and South Carolina. Loup-river Group.	*Conus, Fasciolaria, Cypræa, Pecten, Arca, Janira. Hipparion, Rhinoceros, Tapiravus, Aceratherium, Bos, Morotherium, Protohippus, Pliohippus, Procamelus, Felis, Mastodon.*
	Miocene.	Yorktown.	The Shiloh, Yorktown, and Gay Head Beds. Richmond and Montmery Diatomaceous Earths. White-river Beds. Wind-river Beds. The John-Day basin of Oregon.	*Crepidula, Nassa; Pecten, Chama, Tellina, Lucina. Clypeaster, Scutella. Carcharodon* (C. megalodon), *Galeocerdo, Prionodon. Testudo. Balæna. Miohippus, Diceratherium, Thynohyus, Hyænodon, Hyracodon, Moropus, Oreodon. Merohippus, Elotherium, Brontotherium, Menodus, Dicotyles, Lophiodon, Titanotherium, Rhinoceros.*
	Eocene.	Alabama.	*The Vicksburg Group.* Green-river Shales. The Charleston Burhstones. The Bridger Beds. The Grand-gulf Beds. Orbitoides Limestone. *The Claiborne Group.* White Limestone of Alabama. The Jackson Lignitic Clays. Wahsatch Beds.	*Orbitoides. Oculina, Turbinolia. Clypeaster. Ostrea, Crassatella, Cardita* (C. planicosta), *Cardium, Pseudoliva, Marginella, Mitra, Corbula, Voluta, Panopæa. Lepidosteus, Lamna, Notidamus, Zeuglodon, Carcharodon* (C. megalodon, Ag.), *Galeocerdo* (G. latidens, Ag.). *Emys, Crocodilus, Naocephalus, Thinosaurus. Mesonyx. Limnohyus, Hyrachyus, Orohippus, Colonoceras, Helaletes, Diplacodon, Epihippus, Amynodon, Dinoceras, Tinoceras, Uintatherium,* Coryphodonts, Tillodonts.

[1] Compiled chiefly from the works of Professors J. D. Dana and Marsh. The Palæozoic species common to Europe and America are revised on the authority of Dr. Bigsby's 'Thesaurus.'

[2] The species in ordinary Roman type are those which are found also in Europe.

		Periods.	Local Characters, Names, and Epochs.	Characteristic Genera.
	Transition Tertiary, or Upper Cretaceous.	Laramie.	The Lignitic series of the Mississippi, Upper Missouri, and the Green-river basins. (*These often form productive coal-fields.*)	*Quercus, Acer, Fagus, Juglans, Betula, Cinnamomum, Platanus, Olea, Magnolia, Eucalyptus, Thuja, Sequoia, Taxodium, Flabellaria, Sabal. Corbicula, Melania, Viviparus, Inoceramus, Avicula, Melampus, Physa, Valvata, Fusus, Crassatella ; Ammonites. Lepidosteus, Dinophis. Trionyx. Hadrosaurus, Dryptosaurus, Crocodilus.*
MESOZOIC OR REPTILIAN AGE.	*Later Cretaceous.*	Fox-hills Group.	Sandstones of the Fox-hills, and base of the Big Horn Mountains.	*Trochosmilia, Montlivaltia. Ananchytes, Nucleolites. Fusus, Natica, Nerinæa, Donax, Ostrea, Gryphæa, Exogyra, Cardita, Crassatella ; Hippurites, Caprina ; Nautilus, Ammonites, Scaphites, Baculites; Belemnitella* (B. mucronata). *Mososaurus.*
		Pierre Group.	Plastic Clays of the Upper Missouri.	
	Earlier Cretaceous.	Niobrara Group.	Calcareous marls of the Bluffs on the Missouri.	*Otodus, Beryx, Edaphodon. Atlantochelys. Hyposaurus, Thoracosaurus, Botosaurus, Polycotylus, Tylosaurus, Baptosaurus. Baptornis, Hesperornis, Ichthyornis, Odontornithes. Pterodactylus, Plesiosaurus, Mososaurus.*
		Benton Group.	Clays and Limestones on the Upper Missouri.	
		Dakota Group.	The Rotten Limestone of Alabama and Tennessee. Sandstones and clays with lignites of Dakota, Kansas, and New Mexico.	Leaves of Angiosperms : *Sassafras, Liriodendron, Platanus, Juglans, Salix, Quercus, Acer, Fagus, Ficus, Sequoia, Sabal. Toxaster, Holaster. Cardium, Yoldia, Corbicula, Inoceramus* (I. problematicus), *Pholadomya, Unio ; Ammonites, Scaphites, Hamites, Turrilites, Belemnitella* (B. mucronata).
	Jurassic.	Oolitic, and Liassic.	*Wanting* on the Atlantic and Gulf borders. Marls and Limestone of Wahsatch, the Laramie range, and Uintah. Auriferous slates of the Sierra Nevada.	*Clathopteris. Monotis, Tancredia, Trigonia, Inoceramus, Gryphæa, Unicardium, Myacites, Astarte, Mytilus, Lima ; Rhynchonella ; Belemnites, Ammonites. Pentacrinus. Metacypris. Atlantosaurus, Allosaurus, Morosaurus, Diplodocus, Brontosaurus, Stegosaurus, Camptonotus, Driolestes, Stylacodon, Tinodon, Ctenacodon, Laopteryx, Baptanodon, Sauranodon.*
	Triassic.	The Acadian Area. The Palisade, and other Areas.	Red sandstones and conglomerates of Nova Scotia, the Connecticut Valley, and Pennsylvania, with footprints and ripple-marks. Coal-measures of Virginia and North Carolina. The Elk and Uintah mountains of Colorado, and the Sierra Nevada of California.	*Podozamites, Pterophyllum,* (P. longifolium), *Clathopteris ; Neuropteris, Pecopteris, Cyclopteris, Voltzia* (near V. heterophylla). *Estheria. Spirifer ; Monotis, Myophoria ; Orthoceras, Goniatites, Ammonites, Ceratites. Catopterus. Anisopus, Bathygnathus.* Tracks of Birds? (*Brontozoum*), and Amphibians (*Otozoum*) ; *Belodon, Rhynchosaurus, Amphisaurus. Dromatherium.*

		Periods.	Local Characters, Names, and Epochs.	Characteristic Genera.
Upper Palæozoic or Carboniferous Age.	*Carboniferous.*	**Permian.**	Limestones, sandstones, gypsum, marls, and conglomerates of the Interior Continental Basin west of the Mississippi; Kansas.	*Pseudomonotis, Pleurophorus, Bakewellia, Myalina.* Fishes and Amphibians (*Theromorpha*). *Nothodon, Sphenacodon.*
		Carboniferous.	The Upper and Lower Coal-measures of the Alleghany region, of Illinois, Missouri, Michigan, Rhode Island, New Brunswick, and Nova Scotia; the northern halfof California, and parts of Wyoming and Utah.	*Alethopteris* (A. lonchitica, A. Serlii), *Sphenopteris* (S. latifolia), *Calamites* (C. cannæformis), *Cordaites* (C. borassifolia), *Cyclopteris, Halonia, Lepidodendron* (L. aculeatum), *Lepidostrobus, Neuropteris* (N. Loschii), *Odontopteris, Pecopteris Sigillaria* (S. oculata), *Stigmaria* (S. ficoides). *Fusulina* (F. cylindrica). *Productus, Macrodon, Anthrocosia; Bellerophon; Pupa. Spirorbis* (S. carbonarius). *Leperditia, Estheria; Euproöps, Palæocaris, Eoscorpius. Blattina. Petalodus. Baphetes, Eosaurus, Hylerpeton, Cheirotherium.*
		Sub-Carboniferous.	Conglomerates and sandstones of the Appalachian region, Virginia, and Tennessee. The limestones, sandstones, and shales of Illinois, Kentucky, Iowa, Tennessee, Michigan, and Arkansas. Limestones of Utah, Wyoming, and Northern California.	*Amplexus* (A. coralloides), *Zaphrentis* (Z. cylindrica), *Lithostrontion* (L. cæspitosum). *Pentremites, Poteriocrinus, Actinocrinus, Cyathocrinus, Platycrinus, Athyris* (A. Rossyi), *Chonetes, Orthis* (O. Michelini, var.), *Spirifer* (S. bisulcatus), *Productus* (P. semireticulatus); *Nucula, Conocardium, Aviculopecten, Euomphalus* (E. catillus); *Bellerophon* (B. Urii), *Conularia; Nautilus, Orthoceras, Goniatites. Beyrichia, Phillipsia. Diplodus, Gyracanthus, Cladodus, Palæoniscus, Orodus. Sauropus.*
Middle Palæozoic.	*Devonian or Age of Fishes.*	**Catskill.**	Catskill Red Sandstone.	*Psilophyton, Lepidodrendon, Sigillaria, Cordaites, Neuropteris, Cyclopteris, Caulopteris, Calamites, Prototaxites. Heliolites* (H. interstinctus). *Acervularia* (A. pentagona), *Zaphrentis, Cyathophyllum* (C. helianthoides), *Favosites* (F. Goldfussi), *Aulopora. Actinocrinus, Nucleocrinus. Spirifer, Atrypa* (A. reticularis), *Pentamerus, Stricklandinia, Rhynchonella* (R. cuboides); *Pterinea, Conocardium; Tentaculites; Platyceras; Cyrtoceras. Platyphemera. Eurypterus; Dalmanites, Phacops, Proëtus. Machæracanthus, Coccosteus, Holoptychius, Onychodus, Cephalaspis, Dinichthys.*
		Chemung.	Chemung Shales and Sandstones. Portage Sandstones.	
		Hamilton.	Genesee Shales. Hamilton Flags and Shales. Marcellus Shale.	
		Corniferous.	Corniferous and Onondaga Limestones. (Upper Helderberg.) Schoharie Grit. Cauda-Galli Grit.	

	Periods.	Local Characters, Names, and Epochs.	Characteristic Genera.
Upper Silurian.	**Oriskany.**	Oriskany Sandstone.	*Psilophyton*, *Stromatopora* (S. concentrica), *Heliolites* (H. pyriformis), *Zaphrentis*, *Halysites* (H. catenulata), *Favosites* (F. Gothlandica), *Syringopora*. Graptolites. *Apiocystites*, *Platycrinus*, *Aspidocrinus*, *Cariocrinus*. *Asaphus*, *Calymene* (C. Blumenbachii), *Illænus*, *Homolonotus* (H. delphinocephalus), *Phacops*, *Lichas*, *Proëtus* (P. Stokesii), *Acidaspis*; *Eurypterus*, *Pterygotus*; *Ceratiocaris*. *Strophomena* (S. rhomboidalis), *Rhynconella* (R. cuneata), *Pentamerus* (P. oblongus), *Meristella*, *Atrypa* (A. reticularis), *Orthis* (O. elegantula), *Spirifer* (S. radiatus); *Tentaculites*; *Avicula*; *Holopea*; *Cyclonema*; *Orthoceras* (O. undulatum), *Cyrtoceras*, *Gomphoceras*, *Lituites*.
	Lower Helderberg.	Water-lime Group.	
	Salina.	Onondaga Salt-group.	
	Niagara.	Niagara Shales and Limestone. Clinton Sandstones. Medina Marls and Sandstones. Oneida conglomerates.	
Lower Silurian.	**Trenton.**	Cincinnati Limestone and Hudson-river Shales. Utica Shale. Taconic Slates. Trenton Limestones.	*Buthotrephis*. *Eospongia*. *Receptaculites*. *Stenopora* (S. fibrosa); *Petraia*, *Columnaria*, *Favosites* (F. Gothlandica). *Graptolithus* (G. pristis), *Diplograpsus*, *Phyllograptus*. *Leperditia*, *Primitia*, *Beyrichia*; *Agnostus*, *Amphion*, *Conocoryphe*, *Ampyx*, *Bathyurus*, *Harpes*, *Asaphus*, *Trinucleus* (T. concentricus), *Illænus*, *Lichas*, *Calymene*, *Acidaspis*. *Palæaster*; *Glyptocrinus*, *Dendocrinus*, *Porocrinus*, *Pleurocystites*. *Leptæna* (L. sericea), *Stricklandinia*, *Strophomena*, *Atrypa*, *Discina*, *Lingulella*, *Spirifer* (S. crispus), *Orthis* (O. insularis); *Ambonychia*, *Ctenodonta*, *Conocardium*, *Modiolopsis* (M. modiolaris); *Pleurotomaria*, *Euomphalus*, *Murchisonia* (M. bicincta), *Holopea*; *Maclurea*, *Ophileta*; *Bellerophon*; *Nautilus*, *Lituites*, *Orthoceras*, *Ormoceras*, *Cyrtoceras*, *Phragmoceras*.
	Canadian.	Chazy Epoch: Limestones. Quebec Epoch: Sandstones and Limestones. Calciferous Epoch: Sandrock.	
(Cambrian.)	**Primordial.**	Potsdam Epoch: Sandstones. Georgia Shales and Chilhowee Sandstone. Acadian Epoch: Shales and Sandstones of St. John, Ocoee conglomerate.	*Algæ*, *Eophyton* (E. Linneanum). *Archæocyathus*. *Scolithus*, *Arenicolites*. *Dendrograptus* *Agnostus*, *Paradoxides*, *Conocoryphe*, *Illænurus*, *Dicellocephalus*, *Olenellus*. *Dendrograptus*. *Lingulella*, *Discina*, *Orthis*, *Obolella* (O. Phillipsii); *Theca*; *Pleurotomaria*; *Orthoceras*.
	Archæan.	Huronian. Laurentian.	None? *Eozoon*.

TABLE IV.—LIST OF THE SEDIMENTARY AND METAMORPHIC STRATA OF AUSTRALIA [1].

Age.		Local Formations.	Characteristic Genera of Fossils.
PLEISTOCENE		Black-soil plains. Ossiferous Caves containing extinct gigantic Kangaroos and Emus.	*Diprotodon, Macropus, Nototherium. Notosaurus, Dromornis. Megalania, Crocodilus,* etc.
PLIOCENE		'Deep Leads,' mostly capped by Basalt.	*Spondylostrobus, Penteune, Rhytidocaryon,* etc. (*fossil nuts*).
MIOCENE		Portland Beds of Victoria and 'Deep Leads;' Murray-River Beds of South Australia.	*Belemnites, Pectunculus; Waldheimia, Marginella, Ancillaria, Voluta. Salenia.* Corals.
EOCENE		'Freshwater 'Deep Leads' with Plant-beds. Marine Beds of Victoria.	Leaves of Oak, Maple, Cinnamon, Birch, Laurel, etc.
CRETACEOUS	Upper, Middle, Lower, or Oolitic	'Desert Sandstone' of Queensland. Freshwater Beds of N. S. W. and Queensland. Marine Clays.	*Ichthyosaurus, Plesiosaurus. Ammonites, Belemnites, Avicula,* etc. Coal and plant-bearing beds.
TRIASSIC		'Wainamatta, Hawkesbury, and Clarence Series' of N.S.W.	*Tæniopteris. Palæoniscus. Thinnfeldia* (*Pecopteris*). *Myriolepis. Unio. Zamites, Sphenopteris, Phyllotheca, Tæniopteris.*
		Carbonaceous Series and Bacchus-Marsh Sandstone of Victoria. Ipswich, Burrum, and Clifton Coal Beds of Queensland.	*Gangamopteris, Alethopteris, Macrotæniopteris.*
PERMIAN		Newcastle and Bowenfels Upper Coal-Measures (N.S.W.). Coal-measures, Queensland. Middle Coal Measures of East Maitland (N.S.W.).	*Glossopteris, Gangamopteris, Sphenopteris, Vertebraria, Phyllotheca. Urosthenes.*
CARBONIFEROUS.	Upper	Upper Marine Beds, N.S.W. Lower Coal-Measures ,, Lower Marine Beds ,,	*Spirifer* (S. glaber); *Aviculopecten, Aphanoia, Pachydomus; Orthoceras. Glossopteris, Phyllotheca, Annularia, Noeggerathia.*
	Lower	Port-Stephen's Beds, N.S.W.	*Rhacopteris, Archæopteris, Lepidodendron* (L. nothum).
DEVONIAN	Upper	Brown Sandstones and Quartzites.	*Lepidodendron* (L. nothum), *Cyclostigma, Sigillaria.*
	Lower	Murrumbidgee Beds.	*Spirifer* (S. disjunctus), *Rhynchonella* (R. pleurodon), *Atrypa* (A. reticularis).
SILURIAN	Upper	'Yass Beds,' etc., N.S.W. Mudstones of Yarralumla.	*Phacops* (P. caudatus). *Pentamerus* (P. Knightii), *Atrypa* (A. reticularis). *Cyathophyllum* (C. helianthoides).
	Lower	Slates, Grits, Limestones, Gordon-River Beds.	*Graptolithus, Diplograptus, Didymograptus. Hymenocaris. Siphonostreta, Lingula.*
ARCHÆAN		Gneiss and Schists of Silverton (N.S.W.). Do. of Bathurst and S.W.A.	

[1] Chiefly from information furnished by C. S. Wilkinson, Esq., Geological-Surveyor-in-Charge, Sydney, and T. Edgeworth David, Esq., Department of Mines, Sydney.

TABLE V.—TABLE OF THE SEDIMENTARY STRATA OF NEW ZEALAND[1].

Age.	Local Names.	Characteristic Genera.
RECENT	Moa Beds. Alluvia. Shingle Plains.	*Dinornis, Apteryx. Shell-mounds.*
PLEISTOCENE	Cave Deposits. Shore Deposits.	*Dinornis, Notornis, Palapteryx. Ranella, Voluta, Corninella, Morunga.*
PLIOCENE	Terrace Plains. Alluvial gold drifts. Pumice and Lignite Beds. Kereru Beds.	*Rotella, Dosinea, Struthclaria. Chione, Buccinum.*
UPPER MIOCENE	Wanganui Series. Waitotara and Awatere Beds.	*Ostrea, Chione, Pecten; Murex, Fusus, Struthclaria.*
LOWER MIOCENE	Taipo, Awamoa, Mangapakeha, and Pareora Beds.	*Dentalium, Pleurotoma, Conus. Turritella, Buccinum, Hinnites. Turbinolia. Cucullæa, Conus, Rhynchonella. Schizaster.*
UPPER EOCENE	Mount-Brown Beds. Oamaru Beds. Nummulitic Beds.	Polyzoa and Corals. *Foraminifera. Struthclaria, Pecten, Waldheimia. Terebratella, Meoma. Cidaris, Nucleolites. Carcharodon* (C. megalodon). *Phocænopsis. Kokenodon.*
CRETACEO-TERTIARY	Ototara Stone. Fucoidal Greensands. Amuri Limestone. Coal Formation. Propylite Breccias.	*Oleandridum* (*Tæniopteris*), *Alethopteris. Rostellaria; Belemnites, Ancyloceras. Plesiosaurus, Mauisaurus, Leiodon.*
NEOCOMIAN	Conglomerates with Coal. Porphyries. Greensands.	*Trigonia, Astarte ; Pholadomya. Belemnites, Ammonites.* Saurian bones, and large Chimæroid fishes.
JURASSIC	Mataura Series. Coal-seams. Pututaka Beds. Flag-Hill Beds.	*Cycadites, Camptopteris, Tæniopteris, Macrotæniopteris, Alethopteris, Rhynchonella, Terebratula, Epithyris, Spirifer* (S. rostratus).
LIASSIC	Catlin River and Bastion Series.	*Ammonites ; Clavigera ; Athyris* (?).
TRIASSIC	Otapiri Series. Wairoa Series. Oreti Series.	*Zamites, Rhachophyllum. Pectacrinus. Monotis, Halobia, Clavigera, Tancredia* (T. truncata) ; *Athyris, Spirifer, Rhynchonella ; Psioidea, Pleurotomaria* (P. ornata) ; *Nautilus* (N. mesodiscus), *Belemnites.*
PERMIAN	Kaihiku Series. Mount Potts, and Glossopteris Beds.	*Glossopteris. Ichthyosaurus* (?), Labyrinthodonts (?).
UPPER CARBONIFEROUS	(*Wanting*?).	
LOWER CARBONIFEROUS UPPER DEVONIAN	Maitai Series. Te-Anau Series.	*Spirifer* (S. bisulcatus), *Productus* (P. brachythærus). *Cyathophyllum, Cyathocrinus.*
LOWER DEVONIAN	Reefton Beds.	*Leptæna* (L. bipartata), *Orthis* (O. interlineata), *Spirifer* (S. speciosus), *Chonetes* (C. striatella). *Homalonotus.*
UPPER SILURIAN	Baton-River Slates, and Limestones.	*Orthis* (O. basilis), *Spirifer* (S. radiatus), *Stricklandinia* (S. lyrata), *Rhynchonella* (R. Wilsoni) ; *Murchisonia. Calymene* (C. Blumenbachii), *Homalonotus* (H. Knightii).
LOWER SILURIAN	Mount Arthur Series, and Graptolite Slates.	Encrinite remains, Corals, Graptolites.
ARCHÆAN AND PLUTONIC ROCKS	Gneisses, Mica-schists, Syenites, and Granites.	*None.*

[1] Compiled from the memoir by Dr. Hector in Journal Royal Society New South Wales, 1879, vol. xiii. p. 65 ; with a few additions from Dr. Hochstetter's 'Geology of New Zealand,' and Hutton and Ulrich's 'Geology of Otago,' 1875.

TABLE VI.—List of the Sedimentary Strata of South Africa[1].

Age.	Local Names.	Characteristic Genera.
Recent . . .	Tufa; Shell-breccias; and Blown sands.	Existing plants and shells; bones of existing animals; and stone implements.
Pleistocene? .	Clays, Sandstones, and Lignites of the Cape Flats. Shell-beds and Raised Beaches on the sea-board of the East Province.	
Pliocene ?. . Miocene . . Eocene .	*Wanting.*	
Cretaceous .	Umtafuna and Impengati Beds.	*Ammonites, Anisoceras, Baculites; Fasciolaria, Scalaria, Solarium, Chemnitzia, Euchrysalis, Avellana, Natica, Pollia, Cerithium, Turritella, Dentalium; Ostrea, Inoceramus, Pecten* (P. quinquecostatus), *Trigonia, Arca, Cardium* (C. Hillanum), *Astarte. Hemiaster, Holaster, Diadema.*
Jurassic . .	*Uitenhage Formation.* Trigonia Beds. Wood-bed. Saliferous Beds. Zwartkop Sandstone. } 400 feet. Enon Conglomerate, 300 feet.	Reptilian and Crustacean Remains. *Ammonites, Ancyloceras?, Belemnites, Hamites, Nautilus; Actonina, Alaria, Chemnitzia, Neritopsis, Patella, Turbo; Arca, Astarte, Cardita, Ceromya, Crassatella, Cucullea, Cyprina, Gervillia, Lima, Mytilus, Pecten, Perna, Pleuromya, Trigonia. Cidaris. Isastræa.* (Wood-bed) *Palæozamia, Arthrotaxites, Sphenopteris, Pecopteris, Cyclopteris.*
Triassic . .	*Stormberg Series.* Cave Sandstones, 150 feet. Red Beds, 600′.	*Tritylodon. Eukelesaurus, Orosaurus; Dicynodon, Titanosuchus, Nythosaurus, Procolophon, Batrachosaurus; Rhytidosteus. Extonichthys, Ceratodus.*
	Stormberg Beds, with Coal, 2000 feet.	*Cyclopteris, Pecopteris, Glossopteris, Sphenopteris, Neuropteris, Danæopteris, Palæozamia, Calamites?*
(or Permio-Triassic) . .	*Karoo Series.* Sandstone and Shales, 5000′. Kimberley or Olive Shales and Conglomerates, 2300′.	*Dicynodon, Ptychognathus, Lycosaurus, Tigrisuchus, Scaloposaurus, Platypodosaurus, Galesaurus, Ælurosaurus, Titanosuchus, Cynodracon, Gorgonops, Pristerodon, Talpinocephalus, Theriognathus. Acrolepis, Hypterus,* Palæoniscid Fish Remains. *Glossopteris, Rubidgea, Dictyopteris, Phyllotheca?* Coniferous Wood.
Carboniferous	*Ecca Beds.* Upper Ecca Beds, 2700′. Ecca or Dwyka Conglomerate, 500′. Lower Ecca Beds, 800′.	Plant-remains and Wood. *Lepidodendron, Knorria, Sigillaria, Stigmaria, Lepidostrobus, Halonia, Selaginites.* Coal-beds at Brede River, and Kowie Mouth. *Lepidodendron.*
	Witteberg and Zuurberg Quartzites, } 1000′? Table-Mountain Sandstone, 4000′.	
Devonian . .	Bokkeveld Beds, 1100′.	*Spirifer, Orthis, Terebratula, Productus; Cleidophorus; Orthoceras. Phacops, Homalonotus, Encrinurus.*
Silurian? . . Cambrian? . Archæan? . .	Malmesbury Beds; Mica-schists and Slates of the Cape; Namaqualand Schists and Gneiss.	*None found.*

[1] From 'The Geology of South Africa,' by Professor T. Rupert Jones, F.R.S., British Association Reports of Sections, September, 1884, with subsequent additions.

CHAPTER II.

THE ARCHÆAN ROCKS.

The Archæan Series; their Divisions. The Laurentian and Huronian Rocks of North America. The Pre-Cambrian Rocks of North-West Scotland. The Dimetian, Arvonian, and Pebidian Rocks of Wales. Difference of Opinion respecting these Rocks. Other Archæan Rocks of England. The Archæan Rocks of France, Scandinavia, Germany, the Alps, Spain, India, Africa, Australia, New Zealand, Madagascar, South America.

The Archæan Period. The conditions of the surface at this (the most distant recognisable) geological period were so entirely different from those which subsequently obtained, that it is hardly possible at present to draw the line where the original molten rocks end and the derivative strata commence. With an atmosphere of such a height that the boiling-point of water must have been far higher than it is under the present atmospheric pressure, the earlier aqueous rocks may have been pasty chemical precipitates, or they may have been ordinary deposits, afterwards partially fused when covered by newer strata, and subjected, at great depths and under extreme pressure, to the earth's internal heat. In such cases it may be, as we have before explained, that the eruptive granites, traversing the Lewisian gneiss or the Laurentian rocks, are re-melted early sediments injected during subsequent disturbances and displacements of the strata. But although great heat and pressure might effect radical changes in early sediments when covered up by thick masses of newer rocks,—as are the gneissic rocks of North-Western Scotland, or the felsitic rocks of Wales, by overlying Cambrian and Silurian strata,—they would not affect Archæan areas such as those of North America and Scandinavia, which we have reason to suppose have never been covered, or only to a very slight extent, by newer strata, and which, nevertheless, exhibit either the effects of intense metamorphism, or else the effects of hydro-thermal conditions originally different. This, however, is a subject we have already sufficiently discussed. The rocks we now have to deal with are those only which show distinct, although may be obscure, evidence of sedimentary origin; and of these the earliest known are the Laurentian rocks of North America, and the Pre-Cambrian rocks of this country. They are comprised under the general head of 'Archæan.'

America. The exhibition of these rocks in Great Britain is so small, compared with what it is in America, where, in Canada and the United

States, they extend over many thousand square miles, that we must look to those regions for our types. Notwithstanding this great development, these rocks have suffered such extreme disturbance, present so great variations of petrological structure, and are, with the one solitary exception, so non-fossiliferous, that it becomes a matter of the greatest difficulty to establish the correlation of the several divisions in one area with those in another. Although also the mineral composition may vary in different areas, it is often a question whether this is owing to difference of age and original differences of composition, or whether the differences have been caused by metamorphic action of variable intensity[1].

The broad divisions into a lower or Laurentian series and an upper or Huronian series have, however, been clearly established, as these series occur together, and are in unconformable superposition. To these it has been proposed to add another local group of the White-Mountain rocks or the Montalban. Some geologists would add a so-called Taconic series, but it is doubtful whether these rocks are not Palæozoic strata of Cambrian or later age under exceptional conditions.

Taking the Archæan series as a whole, the essential and important points are, that at the base there exists a great fundamental mass of gneiss and granitoid rocks, overlain by a more varied series of rocks, which, taken in descending order, have been sub-divided, if the Montalban series is to be admitted, in the following sequence :—

	Montalban Series.	—*Micaceous schists and friable gneisses, with chiastolite-slates, quartzites, and crystalline limestones.*
	Huronian Series.	—*Chloritic and hornblendic schists, quartzites.*
Laurentian	Labradorian or Norian group.	—*Gneissoid and granitoid rocks, crystalline limestones, norites, labradorites, and felsites.*
	Grenville group.	—*Gneisses, serpentinous limestones, and dolomites, with beds of graphite and iron-oxides. Zone of the Eozoon Canadense.*
	Ottawa group.	—*Granitic gneisses, generally massive and inclined at high angles.*

The Laurentian series was so termed by Logan in consequence of its large development in parts of the basin of the river St. Lawrence, particularly along the Laurentian range; it is about 30,000 feet thick, and extends over parts of Nova Scotia and New Brunswick, a great part of Labrador, and much of the Lake-district of Canada, and ranges southward to Missouri and New York State. It consists essentially of gneissic rocks very much disturbed and flexured; and this, not locally, but extending uniformly over regions of vast extent. The folds run in long parallel lines, having a common strike. In Canada this strike varies from N. to N.E., the mean being nearly N.N.E. In the United States the strike also is N.E. varying to N.N.E.

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[1] The reader should consult Dana's 'Manual of Geology;' Sterry Hunt's 'Pre-Cambrian Rocks in America and Europe,' and 'The Origin of Crystalline Rocks;' and Whitney and Wadsworth's 'The Azoic System.'

Amongst the subordinate rocks of this series is the beautiful variety of felspar, called labradorite, or Labrador felspar,—a mineral which is very widely distributed. There are also augitic, hornblendic, and hypersthenic rocks, and enormous masses of iron-oxides, sometimes more than a hundred feet thick, together with extensive beds of graphite or plumbago. Amongst the minerals of common occurrence in these rocks are chrysolite, apatite, and blende.

Although the highly crystalline structure of the Laurentian rocks, and the disturbances to which they have been subjected, have in many places almost destroyed the evidence of their sedimentary character, nevertheless the evidently bedded structure of other portions of the formation, the intercalation of beds of limestone, and the presence of some conglomerate beds, leave no doubt of their sedimentary origin. They were long supposed to be unfossiliferous; but in 1859, Sir William Logan discovered in a serpen-

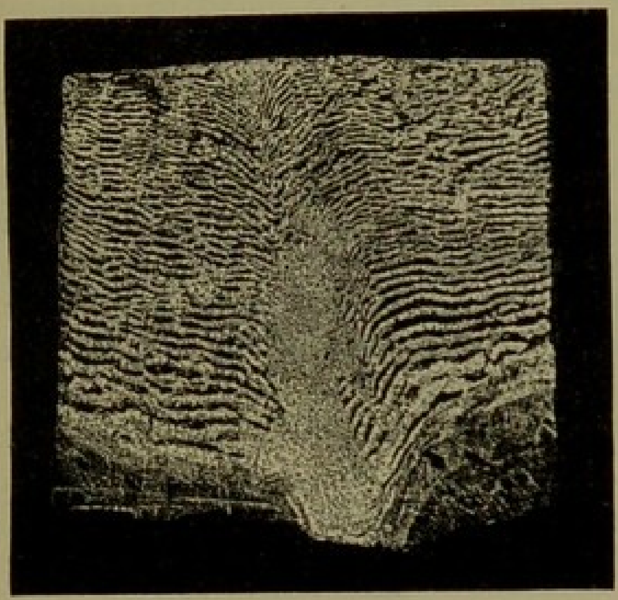

FIG. 2. *Section of rock with Eozoon Canadense, ⅔ nat. size.* (From a photograph by the late Dr. Carpenter.)

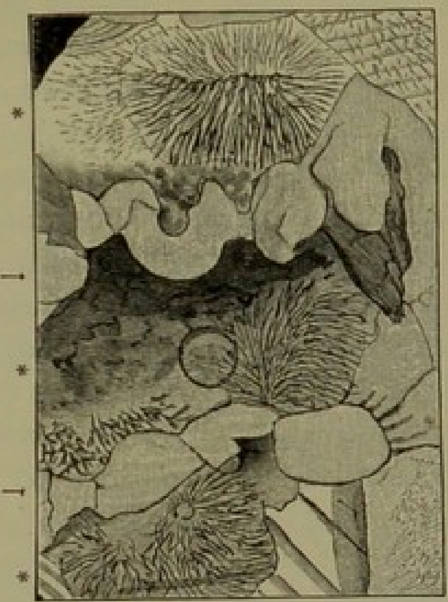

FIG. 3. *Section of Eozoon Canadense, enlarged* 35 *diam.* (Dr. Carpenter). →Infilled chambers (two layers). *Three walls with tubulation.

tinous limestone of the lower division, the indistinct traces of an organism which has been referred to a Rhizopod or Foraminifer of peculiar structure, the *Eozoon Canadense.* Instead, however, of the small organisms formed by the Foraminifera of the present day, the Eozoon built up a continuous calcareous framework, and, like the reef-building corals, of large dimensions.

Sir J. W. Dawson, of Montreal, gave to it the name of *Eozoon*, as representing the earliest form of life; and the late Dr. Carpenter and Professor Rupert Jones, who made this fossil the subject of careful microscopic investigation, assert that its structure is that of a true Foraminifer allied probably to the Nummulinidæ.

This origin has, however, been contested by other geologists, who contend that the structure is of mineral and not of animal origin, and is due to a sort of incipient crystallisation of the metamorphic rock. In Canada, where it can be studied *in situ*, the organic origin of *Eozoon* is more generally accepted. It has been even suggested that some of the great intercalated beds of limestones found in the Laurentian rocks of Canada may have been formed by the succession, layer upon layer, of this early gigantic Rhizopod growth.

Besides this low form of life, there have been noticed on the surface of some of these Canadian rocks, tracks probably of sea-worms or annelids. Beyond these traces, we have no positive indication of life in this vast series of strata. Nevertheless, the occurrence of graphite is on so great a scale, that the quantity of carbon in that state, present in these rocks, is supposed by Dawson to be as large as that stored up in the Coal of some of the great Coal-fields of America; and, as the vegetable origin of mineral coal is beyond question, and as coal is found to pass into anthracite, and even into graphite, the vegetable[1] origin of the latter is not improbable, although no distinct remains of plants have been observed in the associated strata.

The Huronian series consists of conglomerates derived from the Laurentian rocks, of quartzites, felsites, and schistose rocks, intercalated with thin bands of limestone and contemporary beds of diorites, and intersected by dykes of diorite and syenite. Some of the quartzites and sandstones are ripple-marked, but no fossils have been found in these rocks. Dana limits the Archæan to these two divisions.

Scotland. Sir Roderick Murchison considered the Laurentian rocks of America to be represented in the North-West of Scotland by a mass of

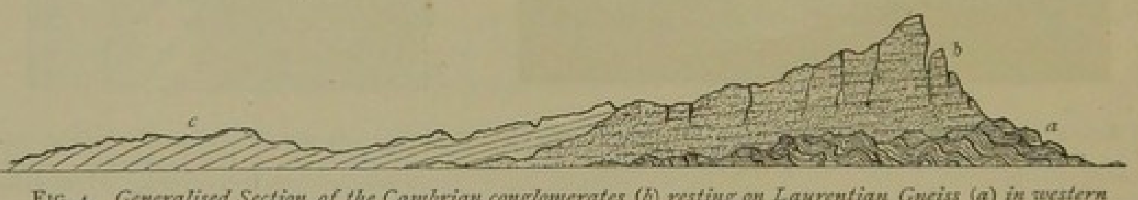

FIG. 4. *Generalised Section of the Cambrian conglomerates* (*b*) *resting on Laurentian Gneiss* (*a*) *in western Rosshire and Sutherland* (Murchison). (*c*) *Silurian Strata.*

highly contorted hornblendic gneiss,—traversed by powerful veins of red granite,—underlying conglomerates supposed to be of Cambrian age, and having a general strike N.N.W. To this he applied the term of 'Fundamental Gneiss,' and subsequently 'Lewisian' from the island of Lewis, which is formed of these rocks.

Since that time the Archæan rocks of Scotland have been found by more recent observers[2] to have greater importance and a wider range. The

[1] Probably from Algæ or Sea-weeds. Land plants do not appear until much later.

[2] See the various papers by Murchison, Nicol, A. Geikie, Bonney, Hicks, Callaway, Hudleston, Lapworth, Marr, and others.

lower hornblendic and upper black micaceous gneisses are now known to be succeeded by more highly quartzose gneisses, micaceous and chiastolite schists and crystalline limestones, supposed to represent respectively the Ottawa, Grenville, and Montalban groups. Further south there are chloritic schists which have been referred to the Huronian series.

In Ireland there are gneissic rocks with micaceous and chloritic schists associated with granite in Wicklow, and gneisses and serpentinous limestones in Galway and Donegal, in all probability of Archæan age.

The Pre-Cambrian Rocks of Wales. Dr. Hicks has shown [1] that below the Cambrian rocks of Pembrokeshire, there is a series of rocks, without organic remains, lying unconformably under, and with a strike different from that of the overlying Cambrian strata. These rocks he has termed Pre-Cambrian, and has divided them into a Dimetian, Arvonian, and Pebidian series.

The Dimetian, the oldest of the series, extend in low undulating hills from the coast near St. David's inland, with a N.W. and S.E. strike. They consist chiefly of granitoid rocks, and quartz-schists, with quartz-porphyries probably of intrusive origin. They are supposed to be not less than 15,000 feet thick.

The Arvonian strata consist of quartz-felsites, *hälleflintas*, and breccias, wrapping round the Dimetian ridge of St. David's. Similar rocks again appear in Anglesea and Caernarvonshire in the same stratigraphical relation.

The Pebidian flank unconformably the older rocks and follow more nearly the strike of the Cambrian rocks. They consist of chloritic, micaceous and talcose schists, of volcanic agglomerates of angular fragments of felstone, green shales, schist, and quartz-rock, derived from the underlying Dimetian and Arvonian strata, embedded in a sea-green felsitic matrix; and of brecciated rocks with associated serpentinous limestones, and volcanic ashes and tuffs. They have the same range as the Arvonian, and an estimated thickness of 8000 feet.

Dr. Hicks refers, though with some doubt, the Dimetian to Upper Laurentian age, and the Pebidian to the Huronian of Canada; in the absence of organic remains this conclusion must rest upon the evidence, somewhat uncertain, of petrological characters and general relative superposition.

These views have, however, been called in question by Dr. Archibald Geikie [2], who contends that the rocks of the St. David's district are not

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[1] 'Quart. Journ. Geol. Soc.,' vols. xxvii. p. 384; xxxi. p. 167; also vols. xxxiii, xxxv, and xxxvi.

[2] 'Quart. Journ. Geol. Soc.,' vol. xxxix. p. 261.

of ante-Cambrian date, but merely mark an episode of great volcanic activity in the Pembrokeshire area at some remote epoch in the Lower-Cambrian period. He conceives that successive showers of volcanic detritus and occasional streams of lava were then emitted from the vents which were at first probably submarine, until a pile of volcanic material, at least 1800 feet thick, had accumulated. As volcanic activity died out, ordinary sedimentation was resumed, and the rest of the Longmynd and the other Cambrian groups were deposited. At a later period, these volcanic rocks and the cotemporaneous early Cambrian strata were disturbed and thrown into a great fold, which was then invaded by a protrusive mass of granite, with the usual peripheral quartz-porphyries; and later again a third and final outbreak of eruptive rocks is indicated by the diabase dykes, which rise through the granite, particularly its central core.

According to this view, while the Pebidian rocks belong to a period of volcanic activity in early Cambrian times, the Dimetian rocks are intrusive granites belonging not to an earlier, but to a later and yet uncertain date. Dr. Hicks, however, maintains that the apparently intrusive position of the granitoid rocks of St. David's is due to powerful faulting, and that there is an absence of any true intrusive junction with the sedimentary strata: and he points out that the conglomerate at the base of the surrounding Cambrian strata consists, in very large part, of materials derived from the Pebidian, Arvonian, and Dimetian rocks, all of which he presumes to have been pre-existent to the whole of the Cambrian series, of which this conglomerate, on his view, forms the base.

FIG. 5. *Outline Map of the old rocks of Charnwood Forest.*

England. The small district of Charnwood Forest, in Leicestershire, forms one of the most interesting geological tracts in Britain. It consists of islets of old slates (Swithland), grits (Bradgate), volcanic ash (Bardon Hill), agglomerates (the Monastery), syenite (Markfield), and granites (Mount Sorrel), rising to heights of 700 to 900 feet in the midst of the surrounding low-lying tract of New Red Sandstone. They are in fact the much weathered and denuded mountain-peaks of an old pre-Cambrian land, swamped and nearly hidden by the newer sedimentary strata which encircle it and fill up the depressions between each protruding ridge. It is a good example of the way in which the features of the early land-surfaces have been obliterated by later changes.

No fossils have been found in any of these rocks, which have been referred by some geologists to Cambrian age, while later observers consider the evidence stronger in favour of their Archæan age[1], on the grounds that their strike is different from that of the Cambrian rocks, and that in the latter there is an absence of volcanic ejectamenta, whereas the Charnwood Forest rocks are, like the Pre-Cambrian of Wales, to a great extent the products of prolonged volcanic action. If of Archæan age, they would

FIG. 6. *Ideal Section through Charnwood Forest.*
a New Red Sandstone; *b* Coal-Measures; *x* Cambrian or Pre-Cambrian Rocks.

probably belong to the upper division, for no true gneiss has yet been found in the Forest area.

In the Wrekin[2] and Lilleshall hills of Shropshire there are granitoid rocks with volcanic agglomerates and felstones (devitrified rhyolitic lavas), which are considered to be of Pre-Cambrian age.

Another fine ridge of Archæan rocks is that forming the main axis of the Malverns[3]. This, which was originally supposed to be an intrusive syenite, has been shown to consist of granitoid gneisses, syenites, hornblendic schists, and flinty argillites of Pre-Cambrian age. The quartzites of Lickey Hill and of Hartshill, near Nuneaton, have now also been shown to be of Pre-Cambrian age.

At places on the south coast of Devon and Cornwall there are micaceous and chlorite schists associated with true gneisses[4] (the Eddystone reefs) belonging in all probability to the Lower Archæan series.

These gneisses again appear on the other side of the Channel in Guernsey and Jersey[5].

France. Laurentian gneisses associated with granites are largely developed in Brittany, and are well shown in many good coast-sections. M. Barrois divides them into a lower granitoid gneiss, and an upper more foliated gneiss with black mica passing into mica-schists[6]. There are also higher beds consisting of chlorite-schists, with silvery schists and serpentinous limestones. Gneissic rocks are again largely developed round the great granitic plateau of Central France, and likewise form part of the Morvan range and of the Vosges mountains. The lower-granitoid series is

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[1] Hill and Bonney; 'Quart. Journ. Geol. Soc.,' vol. xxxiii. p. 754; xxxiv. p. 199; xxxvi. p. 337.

[2] Calloway; 'Quart. Journ. Geol. Soc.,' vol. xxxviii. p. 119.

[3] Holl; 'Quart. Journ. Geol. Soc.,' vol. xx. p. 413; xxi. p. 72.

[4] A. R. Hunt; in 'Trans. Devonshire Assoc.'

[5] Hill and Bonney; 'Quart. Journ. Geol. Soc.,' vol. xl. p. 404; and Liveing, 'Proc. Camb. Phil. Soc.,' vol. iii. Pt. iii.

[6] 'Soc. Géol. du Nord,' vol. ix.

generally surmounted by a garnet-bearing gneiss, mica-schists, serpentines, and crystalline limestones [1].

Scandinavia. But the most important mass of these rocks in Europe is that which constitutes the great Scandinavian range, and extends from Norway into Finland. The lower series consists of massive red and grey gneisses, to which succeed *hälleflintas* and a fine-grained hornblendic gneiss, followed by chloritic and talcose schists, quartzites, and crystalline limestones. There are some conglomerate beds in the centre of the series, probably marking a line of unconformity. As in America, great masses of iron-ore are interstratified with the lower part of this Archæan series, and most of the celebrated iron-mines in Sweden are situated in these rocks. So large are the masses of iron-ore that they constitute entire hills.

In Saxony and Bohemia there is a lower series of grey granitoid gneisses, with orthoclase felspar and white mica of great thickness, surmounted by red micaceous gneisses alternating with mica-schists, hornblendic-schists, cipoline and other rocks of the Huronian type. The upper division forms 'stage B' of M. Barrande. Two doubtful specimens of the Eozoon are reported to have been found in the rocks of Bohemia.

The Alps. Gastaldi has shown that the crystalline rocks of the Western Alps may be divided into two groups: the lower one, which consists of granitic and gneissic rocks, forming the axis of the range of Monte Rosa, he considered to be contemporaneous with the Laurentian rocks of America. Similar rocks have a great development in the Central and Western Alps, where they are associated with mica-schists, chlorite-schists, serpentinous and talcose limestones, forming a mass probably not less than 25,000 feet thick. Later observations lead to the belief that four divisions of the Archæan rocks may be recognised in the Alps. Fig. 7 is a good example of the foliation common in gneissic rocks.

In the Pyrenees and the north of Spain [2] there is but a slight development of gneisses, and as they are intercalated with mica-schists, passing up into garnet-bearing hornblendic schists, with subordinate beds of cipoline, quartzites, and serpentines, it is probable that they represent the Norian and Huronian divisions, and that the Laurentian series is absent.

Archæan gneisses occur also in **Corsica** and **Sardinia**, but little is at present known of them.

In India [3] there are two great 'massifs' of gneissic and crystalline rocks—the one forming the extensive upland and plateau tracts that extend from Ceylon, through the Madras, Bengal, and Bundelkhand districts to

[1] 'Explication de la Carte Géologique de France,' vol. i. chapters ii–vi.

[2] Barrois' 'Terrains Anciens des Asturies et de la Galicie,' p. 398.

[3] This account of the Azoic or Archæan rocks of India is from the 'Manual of the Geology of India' by Messrs. H. B. Medlicott and W. T. Blanford,—a work full of valuable palæontological and topographical details, to which we shall often have occasion to refer.

Assam, a distance of nearly 2,000 miles; the other constitutes the colossal central framework of the Himalayas. There is a marked mineralogical distinction between the gneisses of these two 'massifs,' those of the Himalayas being usually white or grey and the common felspars being orthoclase and albite, while those of the Peninsula are pink and the felspars orthoclase and oligoclase. The former also is more micaceous, and the latter more hornblendic.

Of the Peninsular gneisses, the most northern, or that of the Bundelkhand area, is supposed to be the oldest; the gneisses of Arvali and the Eastern area being considered younger, but their relative ages are yet

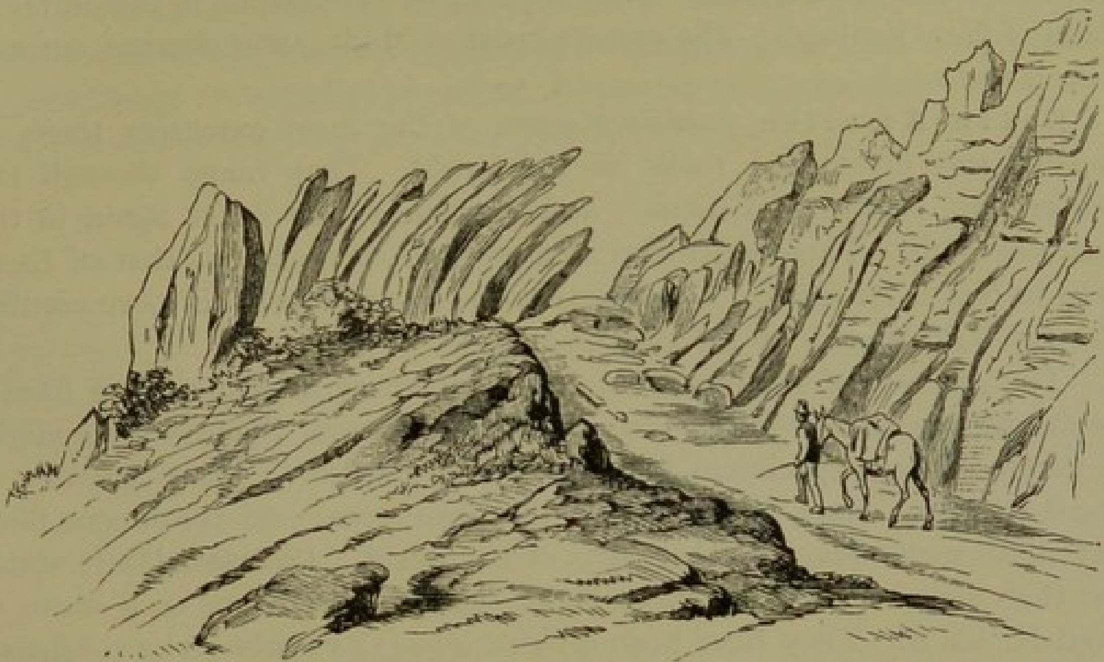

FIG. 7. *Gneissic rocks between the Lower Alp and the Lysthal.* (Schlagintweit.)

uncertain. These gneisses, like those of Europe and America, are characterised by the excessive lateral pressure which they have undergone. Another remarkable feature, common to all countries and before alluded to in vol. I, is the parallelism of the foliation throughout large areas, sometimes extending, as in the Narbada valley, over hundreds of miles. The long, narrow quartz-reefs intercalated with the gneiss, form conspicuous serrated ridges with a strike between 20° and 80° east of north, their mean direction being 36° N.E. Another peculiar feature of these gneisses is their frequent concentric exfoliation, which causes them to weather in huge dome-shaped masses, sometimes rising in hills to the height of 500 to 600 feet.

These Archæan gneisses are succeeded uncomformably by a series estimated at 2000 feet thick, and but little disturbed, of quartzites, conglomerates, schists, slates, breccias, and limestones, associated with contemporaneous bedded igneous rocks. No fossils are found in any part of this series, so that their age can only be inferred from their underlying the great series of the Vindhyan (Palæozoic) strata. They may possibly represent the Huronian series of America.

The gneissic rocks of the Himalayas are supposed to be of two ages—a central gneiss sometimes with large crystals of felspar and with micaceous beds, succeeded by a newer gneiss passing up apparently into slates of Silurian age. This upper division seems to be separated from the lower by a conglomerate bed, and to overlie it unconformably.

In Africa, Archæan rocks form considerable tracts in Algeria and on the eastern borders of Egypt.

In Australasia, gneissic and crystalline rocks occupy large tracts in South-Western Australia. They are also well developed in the northern island of New Zealand. The eastern coast of Madagascar consists entirely of such rocks.

South America possesses some of the most extensive tracts of gneissic and crystalline rocks in the world. They range through the greater part of Brazil, Guiana[1], and Venezuela, and occur again in the Andes of Chili. Their superficial area possibly even exceeds that of those rocks in North America. Geologically, the 'New World' is more entitled than the 'Old World' to the epithet of 'Old.'

The gneisses of Brazil consist of an orthoclase variety, passing from a porphyritic and coarse-grained to a schistose structure. Some of them might be taken in hand-specimens for an ordinary granite[2]. These gneisses of Brazil show the same high dip and the same great and continuous folds that these rocks have in other parts of the world. Professor Hartt states that their strike varies from about N. 40° E. to N. 80° E., or on a mean of about N. 60° E. They have been divided into (1) a lower series consisting of a reddish granitoid and porphyritic gneiss, with fine-grained grey bands: (2) white-banded gneisses, often hornblendic and garnet-bearing. These pass up into mica-schists with quartz bands, and other rocks of the Huronian type. Sterry Hunt considers that the lower series presents all the characteristic types of the Laurentian, while the rocks of the upper resemble those of two of the upper Archæan series of North America.

The larger of the Archæan tracts will be found indicated on the map of the World[3] forming the frontispiece to vol. I. Small as the scale is, it will be evident to the reader that they form *massifs* and continental areas of great extent and of vast dimensions, the importance and interest of which are from year to year attracting more the attention of

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[1] There is a very full petrological account of these gneisses by M. C. Velain, in 'Bull. Soc. Géol. France,' 3rd ser. vol. ix. p. 396.

[2] Hartt's 'Geology and Physical Geography of Brazil,' p. 547.

[3] See also Marcou's 'Explication' of his Map of the World for the range of the several stratigraphical groups.

geologists and petrologists in connection with the physical condition and changes of the crust of the earth in early geological times. These were clearly of a very different order to anything now in operation: they were often due to thermal and chemical causes, and were dependent upon a state of the nucleus and of the atmosphere long since passed away. Formerly, geologists generally attributed these crystalline and schistose rocks to the effects of contact metamorphism, produced by the eruption of igneous rocks through the overlying sedimentary strata, and thought that they might therefore be of any geological age. Instances of such metamorphic changes occur not only in Palæozoic but also in Jurassic and Cretaceous, or even newer strata; they are however all local and on a comparatively small scale, while in the Archæan rocks it is evident that the results were caused by conditions universally prevalent, belonging to a definite period,—and that a period of vast and indefinite length.

CHAPTER III.

THE CAMBRIAN SERIES.

THE DIVISIONS OF THE CAMBRIAN SERIES. THE LONGMYND GROUP. ITS LITHOLOGICAL CHARACTERS AND FOSSILS. THE MENEVIAN GROUP. THE LINGULA-FLAGS. THE TREMADOC GROUP. MURCHISON'S MORE RESTRICTED CAMBRIAN. FOREIGN EQUIVALENTS. FRANCE AND BELGIUM. SPAIN. SCANDINAVIA. BOHEMIA. NORTH AMERICA. NOT WELL MARKED IN ASIA OR AFRICA.

NEXT in succession to the Archæan rocks, and overlying them unconformably, is the Cambrian series, which, in their typical country of Wales, are divided into the following groups (in descending order):—

		feet[1].
Upper Cambrian	Tremadoc Slates	1,000
	Lingula-flags (Ffestiniog group, Sedgwick) ...	5,000
Lower Cambrian	Menevian Beds	700
	Longmynd and Harlech Rocks	12,000
		18,700

The Longmynd and Harlech Group. Stretching N.N.E. and S.S.W. through the West of Shropshire and the borders of Wales, the bold

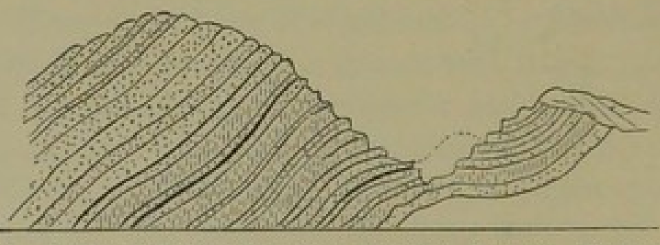

FIG. 8. *Section of the Cambrian Slates and Grits, Penrhyn.* (Ramsay.)

bare range of the Longmynd hills rises to heights of 1500 to 1700 feet, and forms an anticlinal axis, cropping out on the East from beneath Upper Cambrian and Silurian strata, and plunging rapidly (at an angle of about 60°) beneath the same strata to the Westward. The lowest of the Longmynd beds consist of massive conglomerates, alternating with glossy schists; and these are succeeded by purple and greenish flags, grits, and sandstones, which, further to the North-west, where they again rise to the surface, pass upwards into the fine slates so largely worked in the celebrated quarries of Penrhyn and Llanberis.

[1] In this and the following Chapters, it is the mean thickness of the groups or formations in their typical localities that is given.

In the Longmynds the rocks exhibit little, if any, slaty cleavage; but the slates of the same age in Caernarvonshire exhibit cleavage to perfection. The whole series is comparatively free from contemporaneous volcanic matter; nor are mineral veins of frequent occurrence.

Rocks of this age re-appear in South Wales in the neighbourhood of St. David's, where they rest unconformably on the Pre-Cambrian rocks last described; the conglomerates at their base are made up of pebbles derived from the destruction of the older rocks. Some of these included pebbles were apparently metamorphosed previously to their derivation from the parent rock.

As we ascend higher in the Longmynd rocks, ripple-marks occur on the surface of successive beds; and with these ripple-marks are, not unfrequently, tracks and marks, such as those made by Annelids, Crustacea, and Mollusca on a sandy shore. These are repeated through a great thickness of strata. The conclusion is, that, commencing in shallow seas, on the shores of which the Pre-Cambrian rocks were worn down and denuded, the sea-bed gradually subsided, and, as it sank, received fresh sediments, thus keeping the waters shallow so long as the rate of subsidence kept pace with the rate of deposit.

These rocks were long supposed to be unfossiliferous, until Mr. Salter noticed on the surface of some of the rocks of the Longmynd the presence of small pits (Fig. 10 *b*), generally occurring in pairs, which he referred to the borings of some Annelid, from their resemblance to those made by the recent Lob-worm. With these were a few impressions of parts of a Trilobite, allied to Dikelocephalus (*Palæopyge Ramsayi*); but no other fossils have been recorded from that locality.

Of the animal Arenicolites nothing is known, and the term therefore is merely provisional, indicative of its existence only and not of its characters. Just as now the practical observer knows, from the certain marks on the surface, that an Annelid is hidden in the sands beneath, so the existence of analogous forms at this early period is indicated with equal certainty to the practised palæontologist by similar appearances on the now consolidated old sandy surfaces, though the animal itself, having no hard parts, has decayed away.

In Ireland, Dr. Oldham discovered in the schists of Bray Head other peculiar markings (*Oldhamia*), which were at first referred to Zoophytes, but they now are considered to belong probably to sea-weeds, or to minute burrowing Crustacea or Annelids, or even to be of inorganic origin (Fig. 10 *a*).

Since Mr. Salter's researches in the Longmynd, Dr. Hicks has found in rocks of this age in Pembrokeshire, and down to within 500 feet of their base, a much more abundant fauna which brings up the list of fossils,—which are confined to Hydrozoa, Crustacea, Molluscoidea, and one family of Mollusca,—to eighteen genera and thirty-one species [1].

Great interest attaches to this fauna, as, with the exception of *Eozoon Canadense*, which has not yet been found in the Pre-Cambrian rocks of Great Britain, the fossils of this group are the oldest forms of life yet discovered in this country.

In the Longmynd rocks of Wales there are no foraminifera such as the Eozoon, but there are traces of other low forms of life, namely the Sponges, which in some cases cover almost the whole surface of the beds (Fig. 10 *d*).

None of the common recent families of Crustacea existed at this period, but a peculiar order of this class, which is *now* entirely extinct and did *not* survive Palæozoic times, swarmed in those early seas, namely the Trilobita. These creatures, like the larvæ of Limulus, were probably free-swimmers in their young state; and, as is the case with Limulus, they changed their manner of life in their adult state, living then on the bottom of the sea in quiet shallows and deep waters, where they crawled and burrowed in the soft mud in search of food, rolling themselves up like the woodlouse as a mode of protection to their vulnerable ventral surface. While the upper shielded surface is so admirably and abundantly preserved, little is known of the under surface. Dr. H. Woodward has described some appendages which may probably be referred to legs; and tracks have been discovered on the surface of the rocks both in Europe and America, which may have been made by the crawling of Trilobites on the soft mud-flats [2]. These also are the views which the more recent researches of Mr. C. D. Walcott have led him to adopt, and which seem consonant with the geological conditions of the times [3]. Whether or not the remarkable series of foot-tracks found by Sir W. Logan in the Potsdam Sandstone of Canada are referable to Trilobites is yet uncertain. If so, they must have been formed by large species, as the tracks, which have been traced for lengths of many feet, are from 4 to 6½ inches in width. They have been referred also to Eurypteridæ; but Trilobites

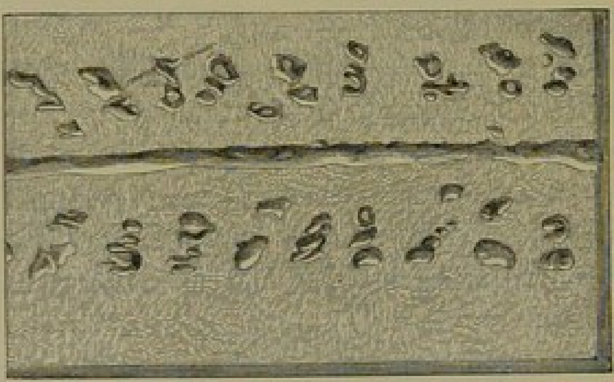

FIG. 9. *Footprints (Protichnites septenotatus*, Owen) *and trail from the Potsdam Sandstone of Canada.*

[1] The numbers in these lists of the Cambrian fossils have been corrected in accordance with Mr. Etheridge's Edition of 'Phillips's Geology,' vol. ii.

[2] Woodward and Billings in 'Quart. Journ. Geol. Soc.,' vol. xxvi. p. 479 and 486.

[3] 'Bull. Mus. Comp. Zoology,' Cambridge, Mass., for March 1881.

would seem the more probable, and species of these of large size are found in the Cambrian rocks of America. Annexed (Fig. 9) is a reduced sketch of one set of these tracks[1].

Trilobites have been divided into thirteen families, distinguished by the number of body-rings, relative size of parts, etc.; each family includes many genera, and these again form numerous species. That they lived gregariously in vast numbers, chiefly of one species, is evident from the crowding of specimens often found on the rock-surfaces.

Remains of seven genera have been found in the Longmynd group of South Wales belonging to two families, namely the *Agnostidæ* and the *Olenidæ* or *Paradoxidæ*. The first is the most simple in form and the smallest in size (¼ inch) of the Trilobites. The body-rings are only two; there are no eyes; and the head and tail are covered by shields nearly equal in size (Pl. I, fig. 1).

The *Olenidæ* or *Paradoxidæ*, on the contrary, have bodies with from eight to twenty-three body-rings, and small head- and tail-shields. They are amongst the largest of the Trilobites, some species attaining a length of more than a foot. The eyes are usually small, and the body-rings are

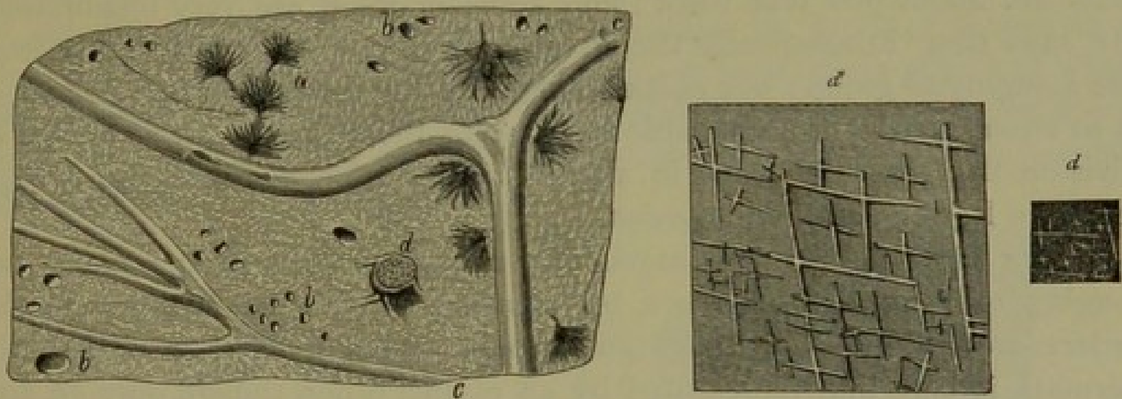

FIG. 10. *a. Oldhamia antiqua*; *b.* burrows, *Arenicolites sparsus*; and *c.* tracks of Annelids, *Scolites* (after Bailey); *d. Protospongia fenestrata*, nat. size; *d'.* enlarged (after Hinde).

mostly prolonged from the pleura, or side-lobes, into spines directed backwards (Pl. I, fig. 4). Altogether thirteen species of Trilobites are found in the Longmynd series, to which the genera *Plutonia* and *Palæopyge* are exclusively confined.

Of the Brachiopoda, three genera existed at this period; namely, *Lingulella*, *Discina*, and *Obolella*; and it is very remarkable that the two former of these belong to families which have survived to the present day. The *Lingulella* in fact very closely resembles the living *Lingula*.

Of the Mollusca proper we only meet with the Pteropoda, the animal of which, instead of being fixed or attached as in Brachiopods, lives in the

[1] 'Quart. Journ. Geol. Soc.,' vol. viii. p. 199.

open sea, swimming on the surface by means of two small fins attached to the sides of the head. They occur in myriads in some parts of the existing seas both in tropical and in Arctic regions; in the latter they serve as food for the whale. The living Pteropods are all of small size, whereas some of the old species were relatively gigantic. Only one species, however, of this class is known in the rocks of this period, a Theca (*T. antiqua*),—a singular form of shell, from one to a few inches long, consisting of a straight sheath tapering to a point, and the mouth covered with an operculum.

The fossils of the Longmynd group are nowhere abundant; the most common forms are:—

Paradoxides Harknessii, *Salt.*	Lingulella ferruginea, *Salt.* Pl. III, fig. 2.
Plutonia Sedgwickii, *Hicks.*	Arenicolites sparsus, *Salt.* Fig. 10 *d.*
Agnostus Cambriensis, *Hicks.*	Protospongia fenestrata, *Salt.* Fig. 10 *d.*
Conocoryphe Lyellii, *Hicks.*	Theca antiqua, *Hicks.*

The Menevian Group. Dr. Hicks[1] has shown that in the neighbourhood of St. David's, as in Caernarvonshire, beds of dark slates with blue and grey flags, which he terms the Menevian Group, overlie apparently conformably the red and purple sandstones of the Longmynd group. These beds are about 600 feet thick; and some of them are very fossiliferous. He says that 'lithologically the Menevian group differs considerably from the Longmynd group; but palæontologically the connection between them is so strong that it is impossible to separate them by any stronger line of division than as sub-groups in a great sub-division.' These two groups form the Lower-Cambrian division.

The Menevian Group contains fifty-two species of organic remains, belonging to twenty-three genera, but showing only a small addition to the orders met with in the Longmynd group. The great class of Echinodermata is here first represented by an extinct order, though only an arm and some indistinct plates of this *Protocystites Menævensis* have yet been discovered; together with Ostracod Crustaceans,—*Primitia* and *Leperditia*.

The other additions to the Fauna consist in the multiplication of the Trilobites, Brachiopods, and Pteropods; but it is chiefly in the former that the main increase takes place. As many as five new genera of Trilobites, all of them peculiar to this group, make their appearance, giving a total of twelve genera and as many as thirty-two species of Trilobites, of which only two genera pass upwards into higher strata. One is the little *Agnostus* and the other the *Conocoryphe*. The most important and characteristic genus of these strata is, however, the *Paradoxides*. This genus in its

[1] For particulars of the Cambrian Rocks of South Wales, and description of their organic remains, the reader should consult the papers of Dr. Hicks in 'Quart. Journ. Geol. Soc.' vol. xxiv, xxviii, xxix, xxxi; and for North Wales the 'Memoirs of the Geological Survey,' vol. iii, by Ramsay. In South Wales the 'Caerfai' and 'Solva' beds form two sub-groups to the Menevian.

abundance and limited localisation is the great feature of the Lower Cambrian ; it does not range higher.

A new genus of Brachiopods here makes its first appearance, namely, *Orthis*, a genus of which the species abounded during the Silurian, Devonian, and Carboniferous periods, but which is not known to have survived the Palæozoic epoch. The more common Menevian fossils are the same as those of the Lingula Flags.

Lingula-flags. Again conformably overlying the Menevian strata in Merionethshire and in Pembrokeshire, is a series of strata consisting of dark slaty rocks, succeeded by arenaceous and micaceous flagstones, passing into soft black slates. This group is much thinner, but more fossiliferous, in South than in North Wales. The lower strata are often very ferruginous; and in some parts metalliferous veins (gold, copper, lead, and zinc) have been found. Workable slates are not common, although in the middle division of the group they are largely quarried at Ffestiniog.

At the time of the discovery of the Lingula (now *Lingulella Davisii*), it was the only known fossil of this group of strata, and from its abundance, its name was applied to the beds. It being also supposed that these were the lowest fossiliferous rocks, they were placed by Murchison at the base of the Silurian series. Amongst the additions to life in this period, is the small phyllopod Crustacean, *Hymenocaris vermicauda* (Fig. 11), which bears a close resemblance to the recent *Nebalia*, common on some shores in shallow water. This fossil is particularly characteristic of the middle division of the Lingula-flags.

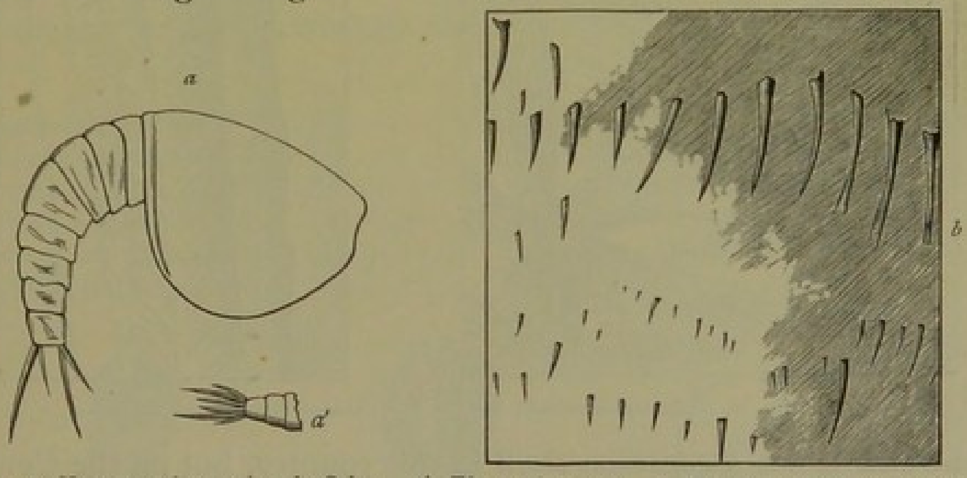

FIG. 11. *a. Hymenocaris vermicauda*, Salter. *a'. The caudal spines. b. Supposed Tracks of Hymenocaris vermicauda*, Salter.

Of the eleven pre-existing genera of Trilobites, nine die out at the end of the Lower-Cambrian period, and only the two before mentioned pass upwards into the Lingula-flags. There are, however, five additional new genera, including the well-marked and characteristic *Olenus*[1].

[1] In some parts of North Wales, and in the neighbourhood of Malvern, the small *Olenus humilis* occurs in such numbers as to have led to the dark slaty beds, which there form the top of the 'Lingula-flags,' being termed the 'Olenus Shales.'

The *Lingulella Davisii* is the important and characteristic fossil of this group of strata. Some of the slates are covered with impressions of this shell variously distorted like the Trilobite, Fig. 14. Another Brachiopod shell occurring in places in thousands is the small Orthis (*O. lenticularis*). It is especially abundant in the upper division of this group.

Annelid markings are not uncommon. Pteropods are scarce, and we meet in these beds with the earliest of the Heteropoda, the *Bellerophon Cambriensis*. This also is a free swimmer, in shape much like some of the Nautilidæ, but having no chambers nor siphuncle. The genus is abundant throughout the Palæozoic series.

Plant Remains, to which the provisional names of *Buthotrephis* and *Eophyton* have been given, are met with. They are very indistinct, and it is yet uncertain whether they are of land or marine growth. The *Cruziana semiplicata*, formerly referred to Algæ, but now to Annelid tracks or Crustacean burrows, occurs in matted masses on the surfaces of some of the arenaceous flags. The characteristic species of the Lingula-flags are :—

Lingulella Davisii, *Salt.*
Orthis lenticularis, *Dalm.* Pl. III, fig. 11.
Anopleurus Salteri, *Hicks.*
Dictyonema sociale, *Salt.* Fig. 12 *a.*
Obolella sagittalis, *Salt.* Pl. III, fig. 1.
Hymenocaris vermicauda, *Salt.* Fig. 11.
Agnostus princeps, *Salt.* Pl. I, fig. 1.
Olenus Scaraboides, *Wahl.* Pl. I, fig. 2.
Paradoxides Hicksii, *Salt.* Pl. I, fig. 4.
Cruziana semiplicata, *Salt.* Fig. 12 *b.*

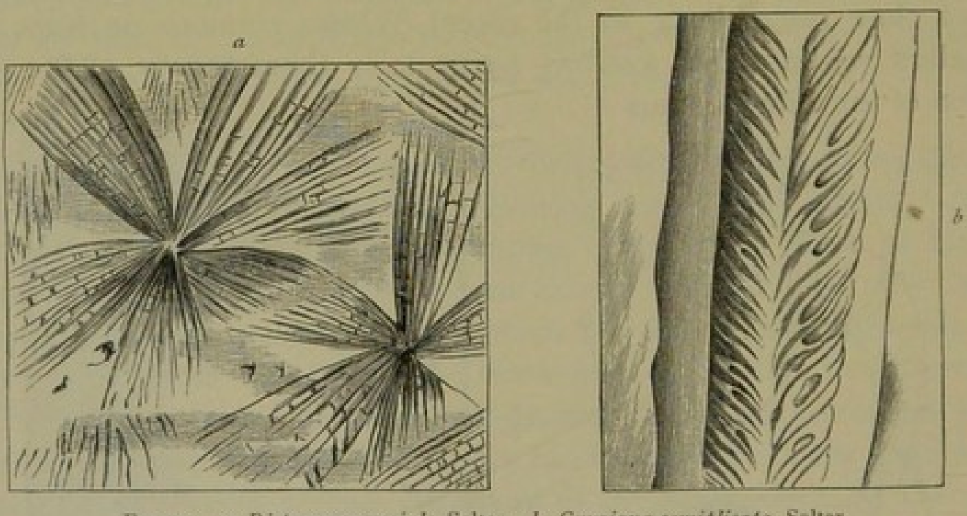

FIG. 12. *a. Dictyonema sociale*, Salter. *b. Cruziana semiplicata*, Salter.

Obolus is not a common shell in this country, but on the Continent, in Sweden and Russia, it occurs in such profusion as to give a name (Obolus-grit) to a zone of rocks. Fossils, on the whole, are very locally distributed throughout the Lingula-flags. They are most abundant near Tremadoc, Dolgelly, and the south end of the Malverns.

The Tremadoc Group—composed of dark earthy slates and flaggy sandstones, more than 1000 feet thick—succeeds conformably to the Lingula-flags. These strata are well exposed in the neighbourhood of Portmadoc in North Wales, and of St. David's in South Wales.

The fossils, which number about sixty-four species, belonging to about thirty-four genera, are, with few exceptions, very much of the same class as those of the underlying beds, though of different species. We note the introduction of two new genera of Trilobites, *Niobe* and *Psilocephalus*, neither of which passes up into the Lower Silurian strata.

These, and all the genera previously noted, belong to the peculiar type of Trilobites considered by M. Barrande as characteristic of his 'primordial zone,' being mostly distinguished by the absence of eyes, the want of the facial suture, and great variation in the number of the body-rings. Their general characters are essentially different from those of the Trilobites of succeeding Silurian age. The Brachiopods are all of the same genera as those in the Lingula-flags.

The most important additions to the life of this period consist in the first appearance of two orders of Echinodermata—the Crinoids and Asteroids; and of two classes of Mollusca—the Lamellibranchiates and Cephalopods; amongst the latter is the genus *Orthoceras*, which swarmed in the seas of the subsequent Silurian period. The Asteroids are represented by a pretty little starfish, *Palæasterina Ramseyensis*. The other is a Crinoid referred to *Dendocrinus* (*D. Cambriensis*), imperfect specimens of which are not rare.

The few Lamellibranchiates which occur are all small, and belong to the Nuculoid form of bivalve shells. Two out of the five genera are confined to this group of strata. The Orthoceras is too indistinct for determination. The characteristic fossils of the Tremadoc group, which is often rich in organic remains, although the number of species continues limited, are:—

Glyptarca primæva, *Salt.*
Lingullela lepis, *Salt.*
Theca operculata, *Salt.* Fig. 13, *a.*
Conularia Homfrayi, *Salt.* Fig. 13, *b.*
Bellerophon Arfoniensis, *Salt.* Fig. 13, *c.*
Asaphus Homfrayi, *Salt.* Fig. 14.
Angelina Sedgwickii, *Salt.* Pl. I, fig. 6.
Niobe Homfrayi, *Salt.* Pl. I, fig. 3.
Psilocephalus innotatus, *Salt.*
Conocoryphe depressa, *Salt.*
Dendocrinus Cambriensis, *Salt.*
Bryograptus Callavei, *Lapw.*

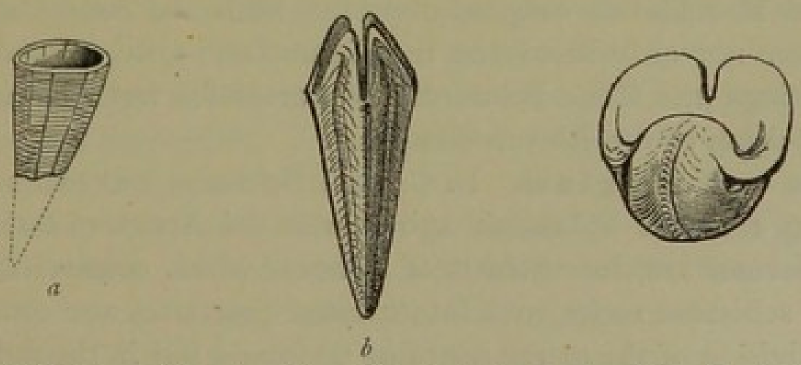

FIG. 13. *Tremadoc fossils. a. Theca operculata; b. Conularia Homfrayi; c. Bellerophon Arfoniensis* (restored).

Sir R. Murchison placed the Lingula-flags at the base of his Silurian system, and thus restricted the Cambrian series to the Longmynd group;

but English geologists generally now carry the Cambrian series to the top of the Tremadoc group. It is true that there is no well-marked physical break at this point, at all events in South Wales, but the palæontological 'break' is of some importance. There are reasons also, to be referred to presently, why physical breaks may then have been of less frequent occurrence (they are somewhat more frequent at this period on the Continent and in America) than at later geological periods. On the other hand, some geologists would follow Professor Sedgwick and extend the Cambrian series to the base of the May-Hill Sandstone, where the first substantial stratigraphical 'break' occurs in the British area[1].

All the fossils of the Cambrian rocks are liable to great distortion in consequence of the compression and shearing which these rocks have commonly undergone. Fig. 14 affords an illustration of this in the case of the Trilobites, showing a squeezing up in one direction and a drawing out in another.

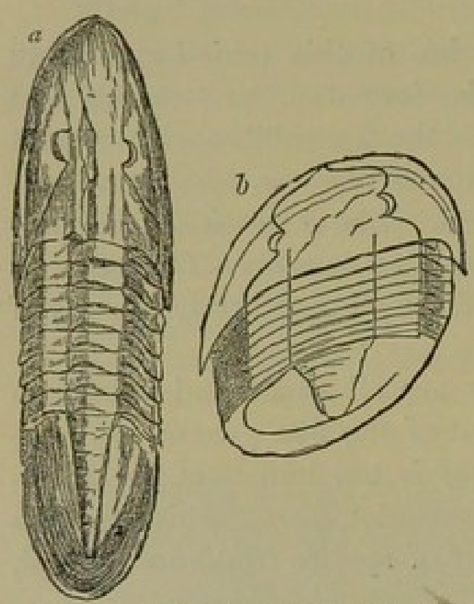

FIG. 14. *Asaphus Homfrayi*: distorted in length (*a*) and breadth (*b*).

Foreign equivalents. Owing to this difference of opinion as to the base of the Silurian series—Murchison contending that it should be at the base of the Lingula-flags, and Sedgwick placing it above the Lower Llandovery,—much uncertainty prevailed for a time as to where the line should be drawn, especially as Murchison had on his side the high authority of the Geological Survey.

If we adopt the view, which is now very generally accepted, that the Cambrian series should not only include the Lingula-flags but extend to the top of the Tremadoc slates, we must be prepared to find that this does not always agree with the classification of Continental geologists, who followed Murchison's original divisions, while the American geologists generally have not only restricted the Cambrian to the formations below the Lingula-flags (the Zone Primordial of Barrande), but have made of this zone a subdivision of the Lower-Silurian.

France and Belgium. In Central Brittany, and extending thence to Cherbourg, rocks of Palæozoic age overlie the Archæan series. At the base of the former are the 'Schists of Rennes' which consist of grey, rose, and greenish schistose rocks, with intercalated quartzites and conglomerates. This lower division of the group contains no fossils, but in the upper division

[1] See Sedgwick's several papers in 'Quart. Journ. Geol. Soc.,' vol. ii, iii, iv, and viii. p. 136, 'On the Classification and Nomenclature of the Lower Palæozoic Rocks of England and Wales;' and his Catalogue of Cambrian etc. Fossils in the Woodwardian Museum; and Murchison's 'Siluria.'

of the 'Red Schists' there are found tangled masses of *Tigilites* which are supposed to represent the casts of gigantic Algæ having a thick cartilaginous stem, and of another supposed fucoid—the *Vexillum*, together with *Oldhamia* and *Arenicolites*[1]. No other fossils have been found in this zone, which is referred to the Longmynd series of Wales.

The conglomerates occur chiefly at the base of the 'Red Schists,' but they are occasionally met with in other parts of the series. None of the more characteristic forms of the Primordial Zone have been found in these rocks, which are at once succeeded by the *Grès Armoricain* containing the common Lower-Silurian forms.

In the Ardennes of the North of France and Belgium, the Cambrian rocks constitute the 'Terrain Ardennais' of Dumont. They consist of the Devillian, Revinian, and, in Luxembourg, the Salmian groups. In the lower of these divisions, in which are situated the well-known slates of Fumay, there have been found *Oldhamia radiata*, *Nereites Cambriensis*, and Arenicolites. In the overlying black schists of Revin are found *Dictyonema sociale*, and *Eophyton Linneanum*; while in the upper schists of Bogny, which are much disturbed and contain interbedded porphyritic and hornblendic eruptive rocks, no fossils have been found.

The lower zone of the Salmian contains some dark-coloured bands with *Dictyonema sociale* and fragmentary remains of *Paradoxides* and *Lingulella*. This is the only evidence there is of the age of these beds. Of the ordinary common invertebrate fossils of the Primordial Zone there are none. In the upper or violet schists of Viel-Salm the well-known hone-stone beds[2] occur.

Spain. M. de Verneuil, Casiano de Prado[3] and others have noted the presence in several provinces of Spain of the Primordial Zone with *Paradoxides*, *Agnostus*, *Orthis*, *Conocoryphe*, *Discina*, etc. Dr. C. Barrois has recently divided the Cambrian of northern Spain into two groups. The lower series or the 'Schists of Rivadeo' attain a thickness of about 10,000 feet, and in these, though generally unfossiliferous, specimens of *Archæocyathus* have been found in places; he considers that this group may be correlated with the Longmynd rocks. The overlying Limestones and 'Schists of Vega,' which are about 400 feet thick and contain species of *Paradoxides*, *Conocoryphe*, *Trochocystites*, *Lingulella*, etc., represent the upper part of the Cambrian[4].

In the Italian Peninsula there are no Palæozoic rocks of any age.

Scandinavia. In the centre and south of Sweden the Cambrian

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[1] Lebesconte et de Tromelin, 'Bull. Soc. Géol. de France,' vol. iv. p. 583, and vol. x. p. 55.

[2] Gosselet, 'Esquisse Géologique du Nord de la France,—Terrains Primaires;' and M. Mourlo, 'Géologie de la Belgique,' p. 27.

[3] 'Bull. Soc. Géol. de France,' vol. xvii. p. 538.

[4] 'Les Terrains Anciens des Asturies et de la Galice,' pp. 406–439.

series is represented by a felspathic sandstone full of impressions referred to markings made by a large sea-weed[1], to which the name of *Eophyton* has been given; together with *Arenicolites* and *Cruziana*. These are overlain by sandstones, also with Algæ, together with a *Lingulella* and a *Dictyonema*. Above these come the black 'Alum-schists' which contain fossils of the Primordial Zone, such as *Agnostus*, *Paradoxides*, *Olenus*, *Conocoryphe*, *Obolella*, *Lingulella*, etc. They are generally of species different from those of Wales, although a few British species are found, such as *Paradoxides Davidis*, *P. Hicksii*, *Agnostus pisiformis*, and *Orthis lenticularis*, which serve to establish relations with the upper Cambrian.

Bohemia. The centre however of greatest importance in Continental Europe is the one made classic by the researches of M. Barrande, who, while Murchison was determining the stratigraphical sequence in this country, was engaged in establishing the life-zones of the corresponding strata in Bohemia, so admirably illustrated in his great work on the subject[2]. His 'Zone *B*,' which overlies unconformably the Archæan rocks of 'Zone *A*,' consists of schistose rocks and grauwackes which were at first supposed, like the Longmynd rocks of Wales, to be unfossiliferous. Similar traces of low forms of life have however since been discovered, consisting of tracks and burrows of Annelids, which render it probable that this zone may be the equivalent of the Longmynd group. Overlying this also unconformably is 'Zone *C*,' or the 'Primordial Zone,' in which the typical genera of Trilobites, including Paradoxides (*P. Bohemicus*), Agnostus (*A. rex*), Conocoryphe (*C. striata*), Sao (*S. hirsuta*, Pl. I, fig. 7), are found, together with species of *Theca*, *Orthis*, etc. Above this zone there is another break, both in sequence and in fossils. None of the genera of Trilobita and no species of the other families pass upwards into 'Zone *D*,' which contains new genera of Trilobita and other fossils of well-marked Llandeilo types. It would appear therefore that 'Zone *C*' represents the middle division only of the Cambrian series; and it may be doubtful whether the upper part of the Tremadoc and the Arenig are not wanting. The break at all events is of importance in establishing a discordance in the sequence which does not exist in Wales, where the succession and conformity of the strata are continued uninterruptedly from the Longmynd to the top of the Lower-Silurian.

It is uncertain whether the Cambrian series, in its typical character, extends further in the South-East of Europe; while in Asia, Australia, and New Zealand, the divisional lines between the rocks of that age (if they there exist) and the Silurian series have as yet failed to be detected.

North America. In the United States and Canada, thick (2000 feet)

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1 Prof. Nathorst has also discovered supposed casts or impressions of Medusæ.

2 'Système Silurien du Centre de la Bohême;' Prague, 1852; and other works.

masses of dark shales, clays, slates, and sandstones, overlie the Archæan rocks unconformably (Fig. 15), forming the lower or Acadian division of the Cambrian series. As in Europe, fossils are rare and confined to indistinct fucoidal remains, burrows and tracks of Annelids (*Arenicolites*, *Scolithus*), Trilobites of the genera *Paradoxides*, *Conocoryphe*, and *Agnostus*, of all of which there are many species (one species of *Paradoxides* attaining a length of 20 inches), together with *Lingulella*, *Orthis*, and *Discina*.

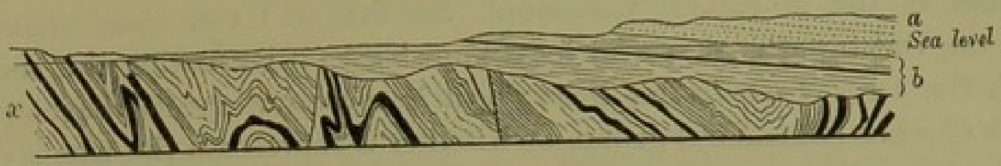

FIG. 15. *Section across the Rivière du Nord.* (Logan.)
a. Potsdam Sandstone. *b*. Acadian Rocks, with track-bed in centre. *x*. Archæan Gneiss with limestone and dykes of trap and granite.

In the overlying Potsdam Sandstone, which often contains local subordinate conglomerates, there is, in addition to the foregoing genera, a great increase in the Trilobita,—*Illænurus*, *Olenellus*, and many other genera now appear,—with Crinoids, Pteropods, and Gasteropods, while the characteristic *Paradoxides* of the Acadian group disappears.

These two divisions form the Primordial or Cambrian group of the American geologists, who make it subordinate to the Lower-Silurian series. The Primordial rocks are chiefly sandstones, with evidence of shallow waters and shifting currents, while those of the succeeding Canadian period are, in the main, limestones deposited apparently in deep and clear waters. There is also some evidence that the Potsdam Sandstone is succeeded *unconformably* by the Calciferous (Canadian) group. These facts show, therefore, that there were at the close of the Primordial Period important physiographical changes, which, accompanied as they were by the disappearance of seven genera of Trilobita and by an entire change of species, would seem to establish a break between this period and the succeeding Canadian period, or the equivalent of our Lower Silurian, as well marked as that which exists in Continental Europe.

In one essential particular, the Cambrian rocks of America differ materially from those of Europe. Whereas here, as a general rule, they are much metamorphosed and altered, in America the alteration is comparatively slight, especially in the Potsdam Sandstone, which more resembles some of our freestones, and is extensively used as a building stone. In some localities there are beds of sands not even cemented.

There is yet another division which has been proposed by some eminent geologists for the older Palæozoic rocks of America, and which has given rise to long discussions, though of an interest local rather than general. The great series of slates, with lenticular intercalated masses of limestones, shales, and sandstones (9000 to 10,000 feet), of the Taconic range of New

York State, contain apparently a peculiar assemblage of Cambrian and Silurian fossils which, in the absence of definite divisions, has given rise to the question whether they all belong to one particular zone under local and abnormal conditions,—or whether they represent the whole of the deeper sea deposits of the early Palæozoic formations, whose more distinctive characters elsewhere are due rather to littoral and shallow water conditions,—or whether it is a case complicated, as in Bohemia, by the presence of the so-called 'Colonies.' So far as I can comprehend the question, which requires special local knowledge, it is whether the series to which the term Taconic has been given is merely a special development of the Quebec (Canadian) group, or whether it represents the whole of the Cambrian and part of the Canadian (lower part of Silurian) series, or is only of Acadian and Potsdam age, or whether it does not even belong altogether to a Pre-Cambrian period[1].

In any case it involves questions relating to priority in nomenclature, and to the distribution of the earliest primordial faunas in the two hemispheres, of importance in relation to their European equivalents.

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[1] See Jules Marcou in 'Bull. Soc. Géol. de France,' 3rd ser. vol. ix. p. 18, and 'Proc. Amer. Acad.' new ser. vol. xii. p. 174; Sterry Hunt, 'Trans. Roy. Soc. Canada,' vol. i. sect. iv; Dana's papers in 'Amer. Journ. Sci.;' and Whitney and Wadsworth in 'Proc. Mus. Comp. Zool. Cambridge, Mass.,' vol. vii.

CHAPTER IV.

THE SILURIAN SYSTEM[1].

Its Divisions. Absence of Unconformity between the Cambrian and Silurian Systems. Restricted Limits of the latter. The Arenig Group. The Llandeilo Group. The Caradoc or Bala Group. The Llandovery Group (the Lower-Llandovery of Murchison). Difficulty of fixing the Boundary-line in parts of Wales. May-Hill Sandstone (Upper-Llandovery). Tarannon Shales. Denbighshire Grits. Woolhope Beds. Wenlock Shale and Limestone. Dudley Limestone. Abundance of Fossils: the Predominant Species. The Ludlow Group: Upper and Lower. Shales and Aymestry Limestone. Tilestones. First Appearance of Fishes. The Silurian Strata of Cumberland: Cornwall: Scotland: Ireland.

Strata of Silurian age form a large portion of Wales and the Border Counties, a district formerly inhabited by the *Silures*, a tribe of Ancient Britons, hence the term 'Silurian' adopted by Murchison.

The classification of Murchison, slightly modified by more recent researches, and excluding the Tremadoc slates and Lingula-flags, placed in the Cambrian system, now stands as follows :—

				Approximate thickness. Feet.
Silurian System.	Upper.	Ludlow Series	Tilestone beds ...	400
			Upper-Ludlow beds ...	500
			Aymestry Limestone ...	150
			Lower-Ludlow beds ...	900
		Wenlock Series	Wenlock Limestone ...	200
			Wenlock Shale ...	1400
			Woolhope Limestone and Shale (and Coniston Flags)	
			Denbighshire Grits ...	1500
			Tarannon Shale ...	
		May-Hill Sandstone (Upper-Llandovery) ...		1000
	Lower[2].	Llandovery Series (lower) ...		1500
		Caradoc and Bala Series (and Coniston Limestone) ...		4000
		Llandeilo Series ...		4500
		Arenig Series and Skiddaw Slates ...		4000

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[1] The special works to consult are,—Murchison's 'Siluria,' 4th edit., 1867; Sedgwick's and McCoy's 'British Palæozoic Rocks and Fossils in the Cambridge Museum,' and papers before referred to; and Salter's 'Cambrian and Silurian Fossils in the Cambridge Museum.'

[2] The term 'Ordovician' has been proposed by Professor Lapworth for the group of Lower Silurian rocks.

THE LOWER-SILURIAN.

The general relation of the lower divisions of the Lower-Silurian to the Cambrian strata is shown in the annexed section by Mr. Salter. A break was made by him and Sedgwick between the Tremadoc and Arenig series in North Wales.

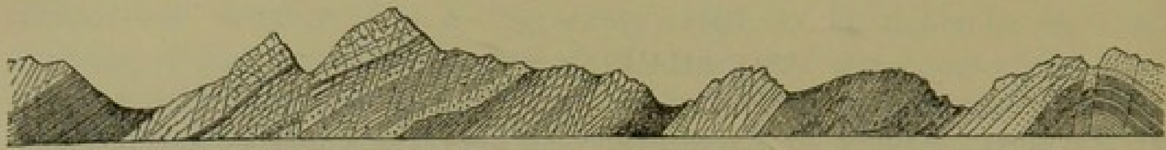


FIG. 16. *Generalised Section in North Wales.*

Part of Caradoc and Bala Series. Llandeilo and Arenig Series. Tremadoc Series. Lingula Flags or Festiniog Group. Menevian Group. Longmynd and Harlech Groups.

Arenig Beds. This group, so named by Sedgwick from a mountain in North Wales, consists of fine black slates interstratified with a few thin sandstones, and with contemporaneous porphyries. These rocks form the peculiar range of the Stiperstone hills—a bold ridge trending nearly parallel to the Longmynd range on their western side, the two ranges being separated by the valleys formed in the softer rocks of Tremadoc and Menevian age. This range, which is much metamorphosed, is conspicuous for bold masses of quartzose rocks projecting through micaceous flagstones. Rocks of the same age re-appear in the neighbourhood of Builth, in the north-west of Wales around Tremadoc, and in the south-west of Pembrokeshire, where black shales and slates prevail.

Through the long succession of Cambrian strata in Wales, the outbursts of contemporaneous volcanic deposits were few. This long period of comparative repose was succeeded in Lower-Silurian times by great and long-continued volcanic action, which commencing in this Arenig group, increased in intensity in the next succeeding or Llandeilo group. Great sheets of interbedded volcanic ash, felspathic porphyries (*p*), and greenstones (*g*) often form mountain-chains, as in the case of Cader Idris, which is built up of volcanic matter alternating with strata of Arenig age, such as is represented in the following section.

The fossils show a considerable increase in number. In place of the fifty-six species, belonging to nineteen genera, of the Tremadoc rocks, there are now 150 species with 63 genera, of which only eleven of the genera pass up from the Cambrian series. The 52 new genera are all of new types, and include many well-known and persistent Silurian forms. Amongst others, Graptolites, so characteristic of Silurian strata, especially predominate; species of the genera *Diplograptus* and *Didymograptus* and others making their appearance in the Arenig rocks. Trilobites are exceedingly abundant; but the peculiar 'Primordial' Trilobites of the Cambrian period no longer continue, with the exception of a few species of

Olenus and *Agnostus*. The genera *Asaphus* and *Calymene*, so abundant in the succeeding group, now first appear.

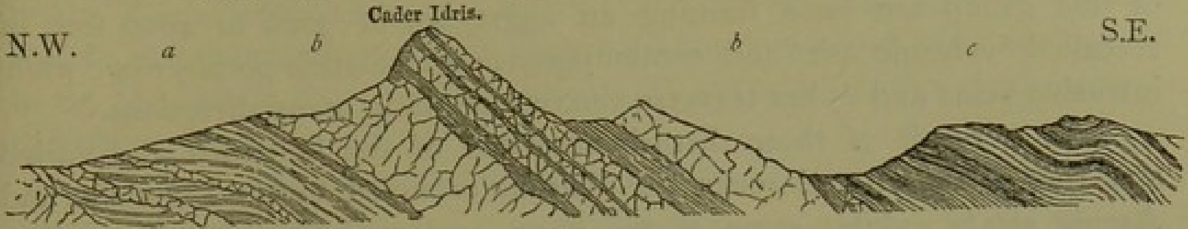
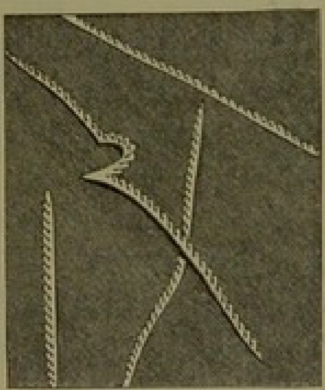


FIG. 17. *Section across Cader Idris.* (After Murchison.)
a. Lingula-flags and Tremadoc slates with bands of Porphyry. *b*. Massive Porphyries and Greenstones alternating with strata of *c*. Arenig and Llandeilo Age.

There is also an increase in the number of Brachiopods, Lamellibranchiates, and Pteropods. Gasteropods commence. Cephalopods are confined to two genera,—Orthoceras and Cyrtoceras. Annelid burrows and tracks, similar to those in the Longmynd, are not uncommon in the strata of the Stiperstone hills. A large proportion of the fossils of this group range into the Llandeilo. Amongst the most characteristic are,—

Lingula petalon, *Hicks*.
Orthis striatula, *Sow*.
Obolella plicata, Hicks.
Bellerophon bilobatus, *Sow*.
Trinucleus Sedgwickii, *Salt*.
Æglina grandis, *Salt*.
Theca simplex, *Salt*.
Palæarca socialis, *Salt*.
Pleurotomaria Llanvirnensis, *Hicks*.
Orthoceras sericeum, *Salt*.
Diplograptus dentatus, *Brogn*.
Didymograptus sparsus, *Hopk*.

a



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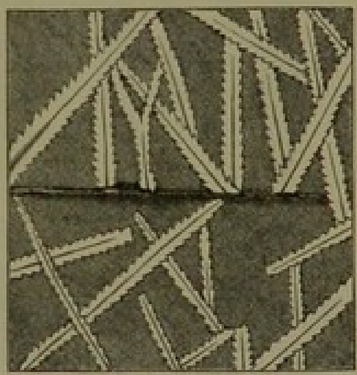


FIG. 18. *a*. *Monograptus sagittarius*, Linn. *b*. *Diplograptus mucronatus*, Hall. (?*pristis*).

The variations in the fauna would seem to warrant the division of the Arenig series, in South Wales, into three groups, each characterised by a particular set of fossils, though closely allied by their general facies [1].

Llandeilo-flags. Next in succession are the Llandeilo-flags, so called from a town in South Wales, where they are well developed. They consist of strata of dark micaceous flagstones, interstratified with black compact shales and slates, with volcanic tuffs, and a few beds of limestone.

[1] Dr. Hicks considers that, owing to the distinctiveness of its fossils, the Upper Arenig might be formed into a separate group,—the Llanvirn.

A remarkable feature of this, as of the last, period is the vast accumulation of rocks of igneous origin. For interstratified with the strata of this group are beds, forming an aggregate of 3000 to 4000 feet, of so-called 'volcanic ash' and contemporaneous felspathic porphyries; while intrusive veins and dykes traverse the rent strata in many directions.

As a result of these disturbances and of the hardened and varied structure of the altered rocks, the districts occupied by the Llandeilo and Arenig strata exhibit some of the finest scenery in North Wales. The bold and effective central pile of Snowdon, rising to the height of 3590 feet, the fine range of Cader Idris, 2914 feet high, and the hills north of Builth, belong to this series of rocks. Not less interesting are the features of the same group in the Lake district of Cumberland and Westmoreland, where the Arenig beds are represented by the Skiddaw Slates.

The organic remains show but a small increase in numbers over those of the last group; but they exhibit some marked distinctions, particularly in the extension of Trilobites. The total number of species is 130, belonging to 60 genera, of which there are only 8 species and 30 genera in common with the Arenig group.

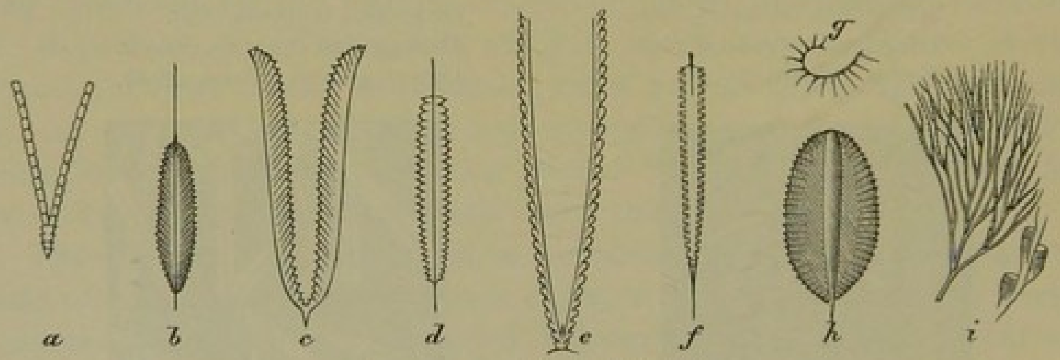


FIG. 19. *Lower Silurian Graptolites.*
a. Dicranograptus Glingani, *Carr.* *b.* Diplograptus folium, *His.* *c.* Didymograptus Murchisonii, *Beck.* *d.* Diplograptus pristis, *His.* sp. *e.* Dicellograptus anceps, *Nich.* *f.* Climacograptus scalaris, *Linn.*, var. rectangularis, *McCoy.* *g.* Rastrites peregrinus, *Barrande.* *h.* Phyllograptus typus, *Hall.* *i.* Dendograptus furcatula, *Salt.*

Graptolites continue in great numbers, and it is a question whether the carbonaceous matter colouring some of the black slates may not be due to the organic matter they furnished. Above 70 species, a large proportion of which are confined to this zone, here occur, the characteristic forms being the double *Diplograptus folium*, Fig. 19, *b*; *D. pristis*, Fig. 19, *d*; *Didymograptus Murchisonii*, Fig. 19, *c*; *Climacograptus scalaris*, Fig. 19, *f*; and *Monograptus sagittarius*, Linn., Fig. 18, *a*.

In Britain no remains of true land plants have yet been found in the Lower-Silurian rocks; but in America they have been recognised by Mr. Lesquereux in the Lower, and by Professor Claypole[1] in the Upper, Silurian. They appear to be related to Sigillaria and Lepidodendron, thus fore-

[1] 'On a Fossil Tree (Glyptodendron) in the Clinton Limestone,' Geol. Mag. 1878.

shadowing, though very faintly, in this early period, a Flora which becomes fairly rich in Devonian times, and attains its greatest profusion in the Carboniferous period. Some thin beds of Anthracite have been found; and, from the rude but numerous impressions of plants, supposed to be fucoidal, in some of the shales and sandstones, this Anthracite is considered to be of vegetable origin.

Amongst other characteristic fossils of the Llandeilo rocks are—

Favosites fibrosus, *Goldf.*
Agnostus M^cCoyi, *Salt.*
Ampyx nudus, *Murch.* Pl. I, fig. 8.
Asaphus tyrannus, *Murch.* Pl. I, fig. 14.
Æglina binodosa, *Salt.* Pl. I, fig. 10.
Ogygia Buchii, *Burm.* Pl. I, fig. 13.
Glytocrinus basalis, *McCoy.*
Orthis calligramma, *Dalm.* Fig. 20 *a.*
Siphonotreta micula, *McCoy.* Pl. III, fig. 13.
Maclurea Peachii, *Salt.* Pl. V, fig. 5.
Murchisonia simplex, *McCoy.*
Orthoceras Avellani, *Salt.*

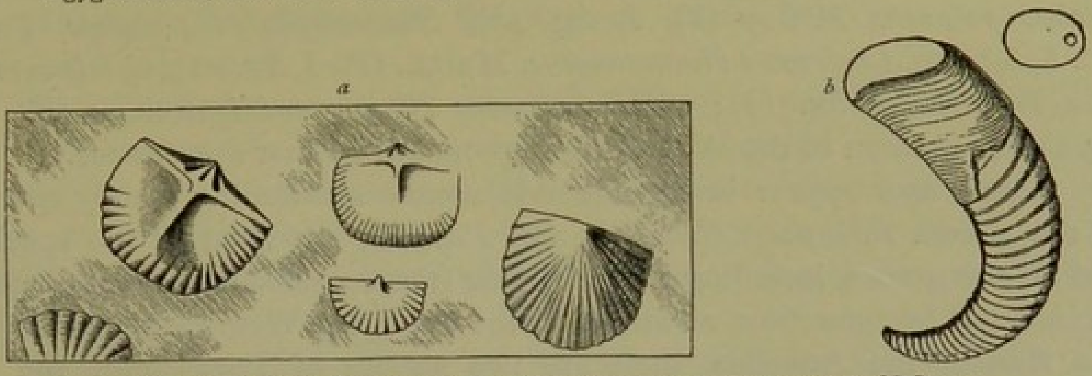


FIG. 20. *a. Orthis calligramma*, Dalm.; *b. Cyrtoceras multicameratum*, McCoy.

The Caradoc Sandstone and Bala Limestone overlie the Llandeilo rocks; the first name having been given by Murchison from the Caradoc hills, and the second adopted by Sedgwick from the town of Bala and its lake. This is the first member of the Palæozoic series in which there is any important development of limestones.

In Shropshire the Caradoc rocks consist of yellow shelly sandstones often calcareous, of building-stones with grits and conglomerates, and of sandy shales, having a thickness of 4000 feet; while in the Bala district they are reduced to 1100 or 1200 feet of black slates with grey and brown sandstones, and a few beds of very fossiliferous impure limestones. Concretions of phosphate of lime form a thin bed in the Bala series of sufficient importance to be worked as a mineral manure.

Volcanic outbursts again took place at the commencement of the Caradoc period, forming great contemporaneous beds of felspathic porphyries and volcanic ash, while at other times the strata were disturbed by intrusive greenstones. They have accumulated in some districts to a thickness of many thousand feet. The picturesque features of the Caradoc and the Berwyn hills are greatly due to the presence of these igneous rocks.

This group has a rich fauna of 614 species, comprised in 179 genera. This gives nearly $3\frac{1}{2}$ species to each genus, whereas in the preceding groups the proportion varied only from $1\frac{1}{2}$ to $2\frac{1}{4}$ to a genus.

Graptolites are less abundant in these strata; the most common species are *Monograptus priodon*, Bronn., and *Diplograptus pristis*, His.

True Crinoids are not numerous; but species of the closely allied extinct order of Cystideans are more plentiful, the commoner forms being *Echinosphærites Balthicus*, Eichw.; *E. Davisii*, McCoy (Fig. 21, *d*); and *Glyptocrinus basalis*, McCoy. Asteroids are represented by *Palæaster asperrimus*, Salt. (Fig. 21, *c*).

Trilobites now attain their maximum development, 123 species having been found in these beds. The prevailing genera are *Asaphus*, *Acidaspis*, *Illænus*, *Phacops*, *Agnostus*, and *Cheirurus*; and the characteristic species are *Asaphus gigas*, Dek., *Phacops apiculatus*, Salt., *Trinucleus seticornis*, His., *T. concentricus*, Eaton (Pl. I, fig. 15), *Calymene brevicapitata*, Portl., *Lichas palmata*, McCoy (Pl. I, fig. 17), *Staurocephalus globiceps*, Port. (Pl. I, fig. 15), *Cheirurus bimucronatus*, Murch. (Pl. I, fig. 11), *Cybele verrucosa*, Dal. (Pl. I. fig. 12); while *Calymene Blumenbachii*, Brongn., (Pl. II, fig. 1), so common in the Wenlock group, makes its first appearance.

Corals also appear in considerable numbers, including mainly species of the genera *Favosites*, *Heliolites*, and *Petraia*; but most of the species, and all the genera, including the *Halysites* (the common Chain-coral), pass up into and become more abundant in the overlying Wenlock group.

Among the Annelids, there are two species of *Tentaculites*, the *T. anglicus*, Salt. (Fig. 21, *h*), and *T. ornatus*, Sby., of which the former is very common; they both range into the Upper Silurian.

A marked feature of this period is the great development of the Mollusca and Brachiopoda. Thus, while in the two preceding groups the total number is only sixty-nine, the number in the Caradoc or Bala group amounts to 312[1], distributed as under:—

	Llandeilo Group. Number of species.	Caradoc or Bala Group. Number of species.
Brachiopoda ...	34	109
Lamellibranchiata ...	6	76
Gasteropoda ...	12	53
Heteropoda ...	7	17
Pteropoda ...	3	10
Cephalopoda ...	7	47
	69	312

At this period the Brachiopoda far exceed in species any other class; but, as we proceed upwards in the geological series, a gradual decrease takes place, and at the present day only six species exist in the British seas. In a similar way the Cephalopods now number only twelve species. The Gasteropoda, however, of which we have fifty-three at the Caradoc

[1] These numbers and those in the subsequent chapters are from the lists given by Mr. Etheridge in the last edition of Phillips's 'Geology,' vol. ii.

and Bala period, amount at the present time to 325, and the Lamellibranchiates to 220 species.

Amongst the Brachiopoda, the genera *Atrypa, Crania, and Rhynchonella* first appear. The common species are *Orthis calligramma*, Dalm. (Fig. 20, p. 47), *O. elegantula*, Dalm., *O. alternata* (Plate III, fig. 9), *Strophomena grandis* (Pl. III, fig. 14), *S. bipartita*, Salt., *Leptæna sericea*, Sby., *L. transversalis* (Pl. III, fig. 5).

A number of new genera of Lamellibranchiates and Gasteropods make their first appearance, such as, amongst the former, *Ambonychia*, *Cardiola*, and *Modiolopsis* (*M. obliqua*, Sby.); and of the latter, *Cyclonema*, *Murchisonia* (*M. turrita*, Portl., and eight others), and *Trochonema*. None of them, however, are very common.

Amongst the Pteropods, the curious genus *Conularia* attains its greatest development.

Lace-like Polyzoa are not rare in the Caradoc and Bala rocks. The more common species is the *Fenestella assimilis*, Lonsd.

Of the Nucleobranchiata, or Heteropoda, there are eight species; of these the *Bellerophon bilobatus*, Sby., is common in this formation in England, and is found in strata of the same age in North America, Spain, and Bohemia.

Three well-marked genera of the tetrabranchiate Cephalopods are very abundant and characteristic, namely *Orthoceras* and *Cyrtoceras*, which commenced in the Cambrian, and *Lituites* which now first appears. Among them are—*Orthoceras angulatum*, Wahl., *O. subundulatum*, Portl. (Fig. 21, *h*), *O. vagans*, Salt., *Cyrtoceras inæquiseptum*, Portl., *Phragmoceras approximatum*, M^cCoy, *Lituites cornu-arietis*, Sby., *Orthoceras tenuistriatum*, Münst.

The Llandovery Series, so called from the name of a small town in Caermarthenshire, is the group next above the Caradoc. Murchison divided it into two parts, including Sedgwick's 'May-Hill Sandstone'; but, as each division has a certain number of fossils peculiar to it, and as the two are unconformable, it is more convenient to retain (as most geologists now do) the Upper as the base of the 'Upper-Silurian series,' under the designation of the 'May-Hill Sandstone,' and to restrict the term 'Llandovery' to the Lower division only. The Llandovery group, as thus restricted, consists of shales, flags, sandstones, and conglomerates, from 500 to 1000 feet in thickness, which pass up without apparent break from the Caradoc-Bala beds, with which it has 103 species of organic remains in common.

Amongst the more characteristic fossils of this group are *Petraia subduplicata*, M^cCoy (Fig. 21, *b*), *Illænus Bowmani*, *Holopella tenuicincta*, M^cCoy, *Murchisonia angulata*, Sby., *Meristella angustifrons*, M^cCoy, *Stricklandinia lens*, Sby. (Pl. III, fig. 4), *Rhynchonella tripartita*, *Pterinea* *retroflexa*, *Nidulites favus*, Salt., etc. A leading feature both of this group and of the succeeding May-Hill Sandstone is the great abundance of species of *Pentamerus*, *Atrypa*, and *Petraia*.

It is chiefly rocks of this age that form the surface of the greater part of Central Wales from the English borders to the coast at Aberystwith.

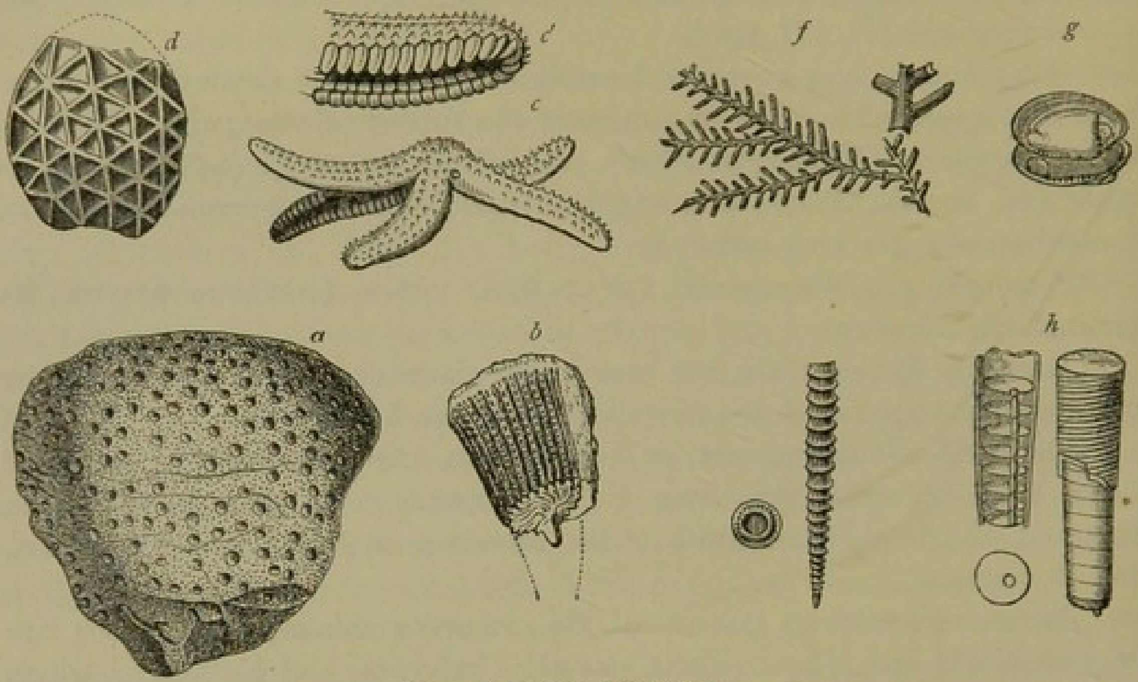


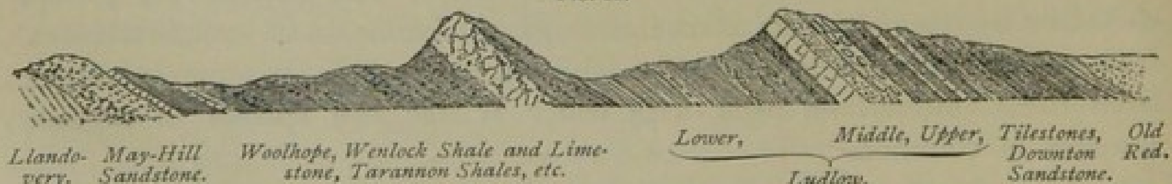
FIG. 21. Caradoc and Bala Fossils.
a. Heliolites interstinctus, Wahl. *b. Petraia subduplicata*, M'Coy. *c. Palæaster asperrimus*, Salt. *d. Echinosphærites Davisii*, M'Coy. *e. Tentaculites anglicus*, Salt. *f. Glauconome disticha*, Goldf. *g. Cucullæa antiqua*, Sby. *h. Orthoceras subundulatum*, Portl.

Not that this area is altogether occupied with the Llandovery rocks, but they predominate so largely, and the boundary-lines between them and the division next below are so difficult to trace, that in most maps they are laid down in one colour.

THE UPPER SILURIAN.

The general sequence of the Upper-Silurian strata is shown in the annexed section from Murchison's 'Siluria.'

FIG. 22.



The May-Hill Sandstone consists of soft sandstones and hard grits, with a basement conglomerate of pebbles derived from the Lower-Silurian rocks, which it overlies unconformably (Fig. 23). It contains a few bands of limestone, one of which is called the 'Pentamerus limestone,' from the abundance of the *Pentamerus oblongus*, Sby. (Pl. III, fig. 12).

These strata are well developed at May Hill near Gloucester, on the West flank of the Malvern Hills near Ledbury, and at Church Stretton. In South Wales they pass transgressively over the Llandeilo rocks (Fig. 23), whilst in North Wales they are wanting.

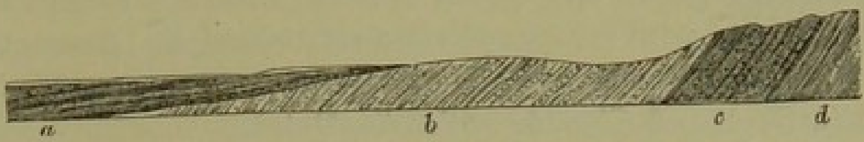


FIG. 23. Section near Hockleton, N. Wales. (Reduced from the Geol. Survey.) *May-Hill Sandstone* (*a*) *overlying Llandeilo slates* (*b*) *and Trap conglomerate* (*c*).

It is in this group that the genus *Pentamerus*, easily recognised by its strong dividing septa, attains its maximum development, no fewer than five out of the eight species of that genus occurring in these beds, and of these five, three are peculiar to this division. The other Brachiopods are mostly of Upper-Silurian forms, and include few characteristic species, these being *Atrypa hemisphærica*, Sby., *Strophonema compressa*, Sby., and *Rhynchonella decemplicata*, Sby. The proportion of Brachiopods to other fossils is again large, amounting to as many as sixty-five out of two hundred and sixty-one species. *Atrypa* and *Stricklandinia* are most abundant genera.

Cephalopods are not so abundant as in the preceding group: *Orthoceras Barrandii*, Salt., is the most common, and the *Tretoceras bisiphonatum*, Sby., the most remarkable species. Of Annelids, the *Tentaculites ornatus*, Sby., and *Cornulites serpularia*, Schl., are plentiful.

Trilobites continue abundant, but there are no characteristic species, *Phacops Stokesii*, M. Edw., *Calymene Blumenbachii*, Brongn., and others being common Upper-Silurian forms.

Cystideans, so common to the Caradoc series, are now rare. Amongst the Corals, the cup-shaped genus *Petraia* (*P. elongata*, Phil.), is very characteristic of both the Llandovery and May-Hill strata, and comparatively rare above and below. *Favosites* and *Heliolites* are not uncommon, and are of the same species as in the underlying and overlying beds. Graptolites are rare, the chief species being *Monograptus priodon*, His.

Etheridge states that out of the whole fauna of 240 species, 104 are common to the underlying Llandovery strata, that 149 species pass up into the succeeding Wenlock group, and that only 91 species are confined to the May-Hill Sandstone.

Tarannon Shales. The May-Hill Sandstone is succeeded in places by a series of pale and light-reddish compact shales and soft slates, with very fine lamination, called Tarannon Shales, from the name of a valley in Montgomeryshire, where they attain their greatest development of about 1500 feet. Fossils are scarce, so that the exact relationship of this division, which is very local, has not yet been accurately determined. It is possibly a local condition of the May-Hill group with some passage-fossils.

Denbighshire Sandstone or Grit. This, the next in order, is also a local group. It is a coarse sandstone, of considerable thickness (3000 feet). Its physical features, rather than its palæontological characters, give this division its importance. It forms hill-ranges of a marked aspect stretching through North and South Wales. Like the Tarannon shales, it contains few fossils, with rather uncertain relationships. Among them may be named *Phacops Downingiæ*, Murch., *Cucullella ovata*, Sby., *Spirifer trapezoidalis*, Sby., and *Chonetes striatella*, Dalm.

Dr. Hicks[1] has recently discovered in these beds distinct traces of land plants—apparently lycopodiaceous wood (*Berwynia Carruthersi*) and seed-vessels filled with spore-like bodies—like the Pachytheca of the Upper Ludlow. These are the earliest indications of a land Flora yet met with in Britain.

Above these groups come the great argillaceous and calcareous strata, with their profusion of organic remains, which constitute so striking a feature of the Silurian series. These strata form, in fact, the backbone of the system, the fossils being as abundant as they are characteristic, and many of them having a very wide range both in time and in space.

Woolhope Beds. This lower sub-division derives its name from the beautiful Valley of Woolhope, where a circle of hills consisting of grey argillaceous concretionary limestones and grey shales, about 1000 feet thick, wraps round a central mass or dome of May-Hill Sandstone. This group also occurs on the West flank of the Malvern Hills.

The fossils of the Woolhope beds are numerous; but, as they are similar to those of the Wenlock strata above them, no separate account of them is needed—unless it be to notice two peculiar Trilobites—the *Homalonotus delphinocephalus*, Green, and *Illænus Barriensis*, Murch.

Wenlock Shale and Limestone. The last group passes upwards into the thick mass of soft calcareous shales, generally light-coloured, capped by massive grey limestones, which constitute the Wenlock group,—so called from the town of that name. The Shales attain a thickness of from 1000 to 1500 feet, and the Limestone of from 100 to 200 feet. This disposition of the strata gives rise to some marked physical features. Stretching through south-western Shropshire in an almost straight line from S.W. to N.E., the limestone, from its greater hardness, stands out and forms the fine escarpment of Wenlock Edge, while at its base stretches the broad valley excavated in the soft Wenlock Shales.

The Limestone is generally concretionary and argillaceous, and worthless as a marble, but useful as a flux in smelting iron; and the light-

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[1] 'Quart. Journ. Geol. Soc.,' vol. xxxvii. p. 482, and vol. xxxviii. p. 97.

grey or greenish calcareous shales contain small flattened nodules of grey earthy limestone. The Wenlock beds are also well exhibited at Dudley, where the picturesque hill known as the Wren's Nest is formed by the scarped and tilted circular outcrop of the limestone.

The Wenlock Limestone is singularly rich in fossils: in fact, like many other limestones, it is largely composed of them. It is difficult to take up a fragment which does not exhibit organisms more or less perfect. Whole beds are composed of the detached plates and columns of various Crinoids; while Corals of varied forms, and Polyzoa, are scarcely less numerous. The many quarries in the neighbourhood of Wenlock, and at Lincoln Hill near Ironbridge, the weathered slopes of Benthall Edge, and the great quarries near Dudley, afford endless supplies of beautiful fossils. It is a wonderful scene of the profusion of life during that early geological period.

The shales also, although seemingly poor in fossils, contain in places innumerable minute and young forms of life. These, however, are only to be had by washing the shale. By adopting this process Mr. George Maw [1] obtained from one cartload of Wenlock Shale from Buildwas at least 10,000 specimens of young and minute Brachiopods. No less than 4,300 of these belonged to one species—the *Orthis biloba.* Besides these there were an uncounted number of minute Corals, Ostracods, and other fossils.

By similar careful observation, an addition to the Palæozoic fauna has been made of late years, which may help to clear up those obscure manifestations of life so common in early geological times,—the casts and impressions ascribed to the tracks and burrows of Annelids. Traces of the presence of these worms are plentiful, but owing to their soft structure, and the very small size of their few hard and detached parts, there seemed little prospect of any portion of the animal itself being discovered.

Some years ago Pander found, in the lowest Palæozoic rocks of Russia, some very small serrated bodies, termed Conodonts, which he referred to fishes' teeth. Dr. Newberry, who afterwards found them in the Carboniferous strata of America, considered that they might belong to Myxinoid fishes. Some of them have also been referred to the prickly processes of Crustacea. Dr. G. Hinde has obtained them in America from the lowest Silurian (Chazy) to the Carboniferous strata. Associated with these in the Silurian strata of America, Gothland, and in the Upper Silurian Strata of England, Dr. Hinde has discovered other microscopic bodies, namely, the jaws of Annelids, allied to the existing Eunicea (Fig. 24). These minute objects are smooth, black, and polished, with a chitinous structure, and vary from $1\frac{1}{4}$ to $2\frac{1}{2}$ lines in length. They are more or less abundant in intercalated shales of the Wenlock Limestone at Dudley, Much Wenlock, and Iron Bridge, where they have furnished twenty-five forms belonging to four

[1] 'Geol. Mag.' Dec. ii. vol. viii. March 1881.

groups[1]. Annexed are greatly enlarged figures of the four most common genera.

The Wenlock shale is also very rich in fossils on the Western slopes of the Malvern Hills, where the beds are more compact and intercalated with bands of impure argillaceous limestone. Trilobites especially abound. Their numbers and the marvellous way in which they are preserved in all attitudes—some in a natural position, others writhing and distorted, as though they were suffocated — is very remarkable. The cutting of the railway-tunnel yielded to the assiduous labours of Dr. Grindrod a grand collection (now in the University Museum of Oxford) of thousands of these Crustaceans in all stages of growth.

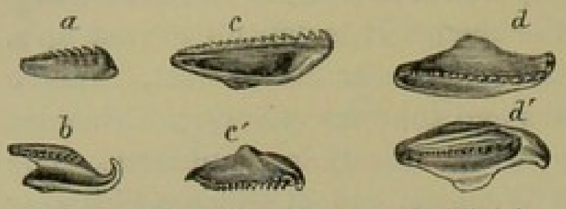


FIG. 24. Wenlock Annelid jaws. (After Hinde.)
a. Eunicites serrula, H. *b. Arabellites spicatus*, H. *c., c'. Œnonites major*, H. *d., d'. Lumbriconereites obliquus*, Eichwald.

Another abundant form is the equivocal *Stromatopora striatella*, d'Orb., which was originally supposed to be a Coral, then a gigantic Foraminifer, afterwards a peculiar type of Sponge, or a Hydractinid.

Graptolites, so abundant in the Lower Silurian, are now rare and reduced to the Monoprionidian forms alone, *i.e.* those which have but a single row of cellules. The genus *Rastrites* is also absent. The few species which do occur are confined to the genera *Monograptus* and *Retiolites*; the *R. Geinitzianus*, Barrande, is peculiar to the Wenlock Shale.

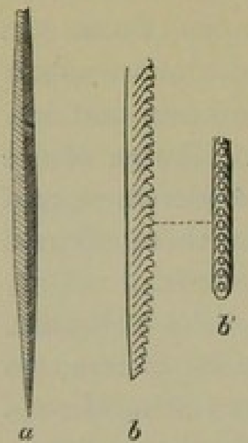


FIG. 25. Upper Silurian Graptolites.
a. Retiolites Geinitzianus, Barr. *b, b'. Graptolithus* (Monograptus) *priodon*, Bronn.

Corals are extremely plentiful, much of the Wenlock Limestone being in fact an old Coral-bank, where hundreds of specimens of the genera *Halysites* (Chain-coral), *Favosites* (sometimes a foot or more across), *Heliolites*, *Cœnites*, and *Syringopora* may be collected in the course of a morning.

The genera *Fistulipora* and *Strombodes* make their first appearance, together with the curious operculated Coral, the *Goniophyllum* (G. pyramidale, Fig. 26, *d*). Amongst the characteristic species are *Halysites catenulatus* (Fig. 26, *b*), *Favosites Gothlandica*, Lam. (Fig. 26, *e*), *F. cristatus*, Blum., *Heliolites interstinctus*, Wahl., *H. tubulatus*, Lons., *Syringopora bifurcata*, Lons., *Omphyma subturbinatum*, Linn.(Fig. 26, *a*), *Cystiphyllum cylindricum*, Lonsd.(Fig. 26, *c*). Altogether, there are fifty-three known species of Corals in these beds.

Of the Crinoids, the most common are the several species of *Cyatho-*

[1] 'Quart. Journ. Geol. Soc.,' vol. xxxv. pp. 351, 370, and xxxvi. p. 368. Swedish Acad. Sci., Sept. 1882.

crinus,—a genus peculiar to this formation. There is also the *Periechocrinus moniliformis*, Miller (Fig. 27, *c*), with its large bead-like stem, and the

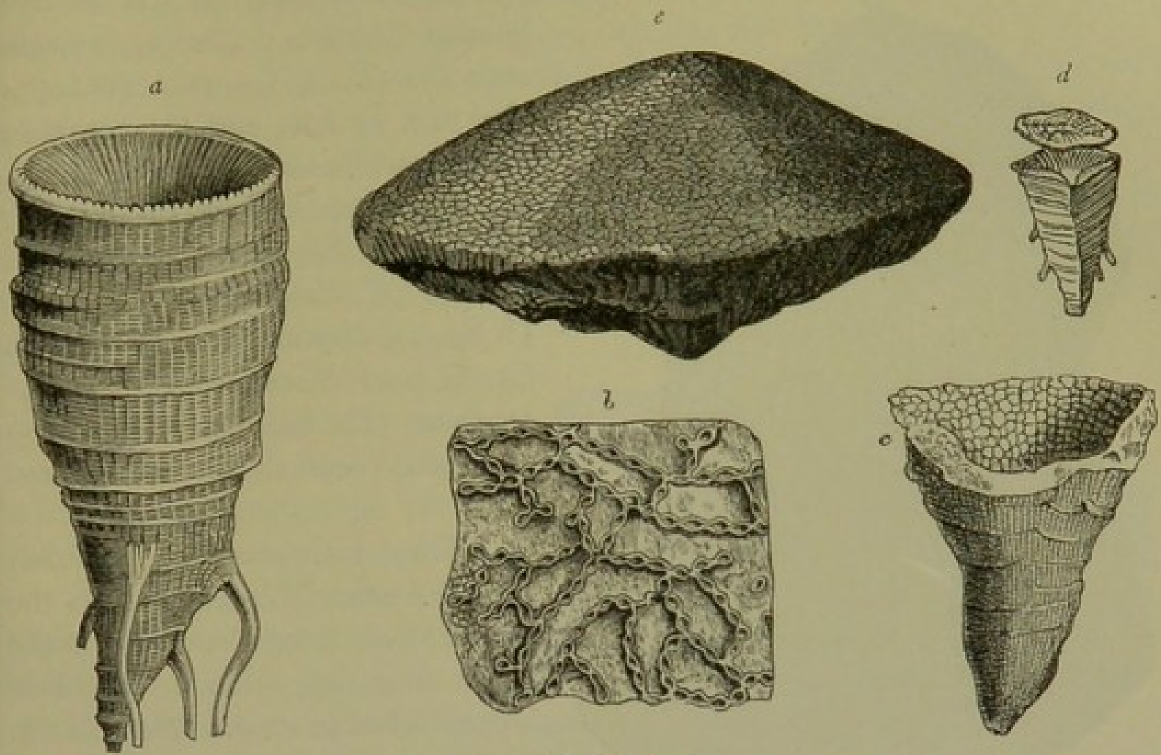


FIG. 26. Wenlock Corals.
a. Omphyma subturbinatum, D'Orb. *b. Halysites catenulatus*, Linn. *c. Cystiphyllum cylindricum*, Lonsd. *d. Goniophyllum pyramidale*, His. *e. Favosites Gothlandica*, Lam.

singular *Crotalocrinus rugosus*, Miller (Fig. 27, *b*). The curious Cystidean, *Pseudocrinites quadrifasciatus*, Pearce, is found at Dudley, but it is rare.

The genus *Actinocrinus*, which ranges up to Carboniferous times, now first appears. There is a beautiful bunch of one species in various stages

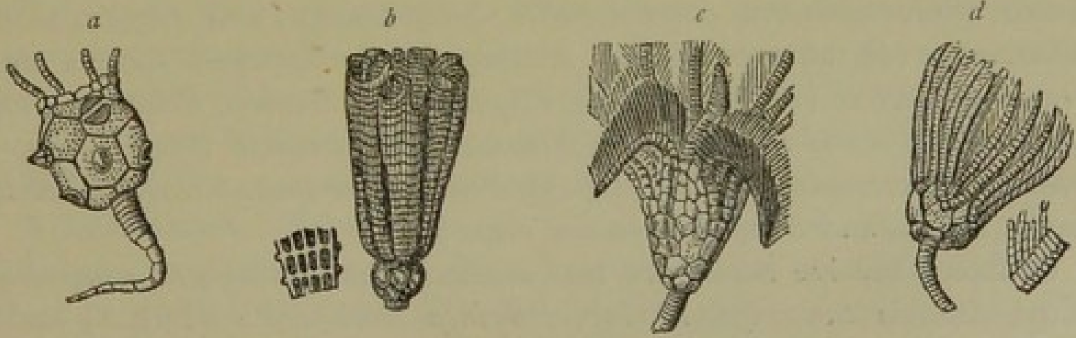


FIG. 27. Wenlock Crinoidea. (After Salter.)
a. Echino-encrinites armatus, Forbes. *b. Crotalocrinus rugosus* (Mill). *c. Periechocrinus moniliformis*, Mill. *d. Marsupiocrinus cœlatus* (Phil.).

of growth (1 to 4 feet long) on a slab of hard metamorphosed Wenlock shale in the Oxford Museum, of which the annexed figure is an imperfect representation (Fig. 28).

Trilobites are exceedingly abundant in some places, and, as a rule, they are more highly ornamented than the more ancient species. Among the most characteristic may be named the *Encrinurus punctatus* (Pl. I, fig. 9), known as the strawberry-headed Trilobite; *Cheirurus bimucronatus* (Pl. I, fig. 11), *Acidaspis Brightii*, Murch., and the common *Calymene Blumenbachii* (Pl. II, fig. 1), the best known of all the Trilobites. *Phacops caudatus*, (Pl. II, fig. 5), *Illænus Barriensis* (Pl. II, fig. 2), *Proëtus Stokesii* (Pl. II, fig. 6), and *Homalonotus delphinocephalus* (Pl. II, fig. 7), are also common Wenlock Limestone fossils.

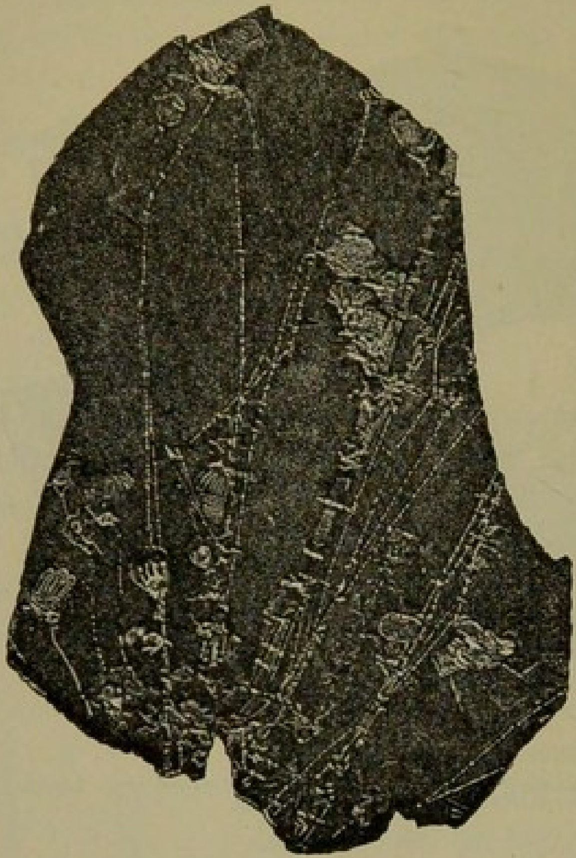


Fig. 28. *Actinocrinus pulcher*, Salt., *on a slab* (4 by 2½ feet) *of Wenlock Shale, Llangollen.*

The Eurypteridæ, together with the other Merostomata to the number of thirty species, make their first appearance in these Upper-Silurian strata. None of the higher order of Macrourous Decapods yet appear. Of the Entomostraca, Phyllopoda are not numerous (*Ceratiocaris*); small Ostracod Crustaceans, however, of the genera *Leperditia*, *Beyrichia*, and *Primitia* are of not infrequent occurrence.

Brachiopods, although not so predominant as in the Lower Silurian, are still very numerous. *Orthidæ* and *Lingulidæ* especially are much less frequent, while *Spiriferi*, *Rhynchonellæ*, *Strophomenæ*, and *Atrypæ*, mostly of small size, are more common. Among the characteristic species are,—*Spirifer plicatellus* (Pl. III, fig. 10), *Rhynchonella borealis*, Schloth., *Orthis rustica*, Sby., *Atrypa marginalis*, Dalm., *A. reticularis* (Pl. III, fig. 6), *Leptæna transversalis* (Pl. III, fig. 5), *Pentamerus galeatus*, Dalm., *Retzia cuneata*, Dalm., and *Strophomena depressa*, Sby.

Ordinary bivalve shells are less common, but *Orthonota semisulcata*, M^cCoy, *Avicula Sowerbyi*, M^cCoy, *Pterinea Danbyi* (Pl. V, fig. 1), and *P. planulata*, Conrad, are abundant species. *Mytilus mytilimeris*, Conrad, *Modiolopsis antiqua*, Sby., and *Cardiola interrupta*, *Grammysia cingulata* (Pl. V, fig. 2), Sby., are also characteristic. Professor Phillips has pointed out the curious fact that in these ancient strata this class of shells consists chiefly of families represented by the recent genera *Avicula*, *Nucula*, and *Mytilus*.

Gasteropoda are not abundant, with the exception of *Euomphalus*, of which there are four species, some of them being extremely common. *E. funatus*, Sby., and *E. rugosus*, Sby. (Fig. 29, *c*), are the most common, and have the greatest vertical range. *Murchisonia Lloydii*, Sby., and *Acroculia Haliotis*, Sby. (Pl. V, fig. 4), are also not rare.

Of the Pteropods and Nucleobranchiates the species are few, but well marked. Amongst them are *Theca Forbesii*, Sharpe, *Conularia Sowerbyi*, Defr., and *Bellerophon Wenlockensis*, Sby.

Cephalopods, abundant in the Caradoc group, show a marked decrease in the Wenlock Limestone; but a limited number of species, such as *Orthoceras annulatum*, Sby. (Pl. V, fig. 7), and *O. fimbriatum*, Sby., are common, and certain thin-shelled species, such as *O. subundulatum*, Portlock, are of frequent occurrence in the Shales of this series. *Phragmoceras* and *Lituites* are rather characteristic than abundant.

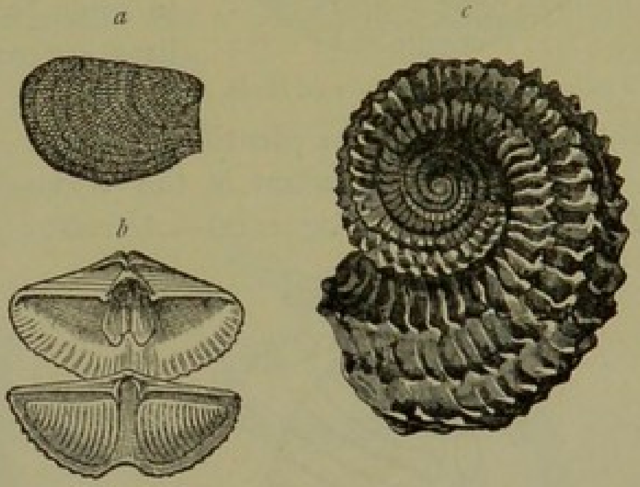


FIG. 29. Other Wenlock Fossils.
a. Pterinea mira, Barr. *b. Spirifer trapezoidalis*, Dahl. (*Cyrtia exporecta*, Wahl.) *c. Euomphalus rugosus*, Sby.

The Ludlow Formation, so called from a town of that name in Shropshire, follows next in succession to the Wenlock. It consists in Shropshire of a central mass of limestone, called the Aymestry Limestone, with shales above and below, making a tripartite division, but elsewhere only two divisions are recognised.

Apart from the local Aymestry Limestone, the chief mass of the Ludlow formation consists of grey, argillaceous, micaceous shales, often sandy and fissile, with calcareous concretions. Many of the shales of the Ludlow group have undergone so little change, that on exposure to the weather they soften into a silty sediment, such as the original mass probably consisted of before consolidation. Whence the term of 'Mudstone.'

The Upper-Ludlow beds are succeeded by the Downton Sandstone, the beds of which, generally fissile and of a red colour, are locally known as **Tilestones.** From its colour and lithological character, it was formerly classed with the Old Red Sandstone; but its fossils, which are rare, show stronger relations with the Silurian series, of which it now constitutes the highest member. It sometimes passes into a good building-stone, as at Downton Castle near Ludlow, where it is largely quarried.

The Ludlow group is best exhibited in the neighbourhood of Ludlow and Aymestry, where the central limestone forms an escarpment parallel with that of Wenlock. It is also well seen in the district west of the Malvern Hills, and at Sedgely. From the railway-cuttings west of the Malvern Hills Dr. Grindrod obtained a very large number of fossils.

The organic remains, as a whole, show many features in common with the Wenlock series. The lower argillaceous division especially might be grouped with it, so many species are common to the two. Still, in ascending, important new forms of life appear, which give a marked type to the period, and a considerable number of species are characteristic of the Ludlow group. The curious Silurian globular sponges (*Ischadites*) with their symmetrical reticulated surfaces are especially developed in some parts of the Ludlow series. Graptolites are reduced to very few species; but one of the old forms (*Graptolithus priodon*, Bronn) still continues plentiful in places.

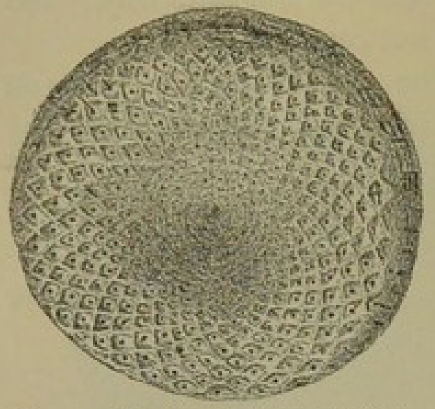


FIG. 30. *Ischadites Lindstræmi*, Hinde.

Corals, so abundant in the Wenlock, are now comparatively scarce. A singular encrusting coral—*Alveolites fibrosus*, Lonsd.—is however fre-

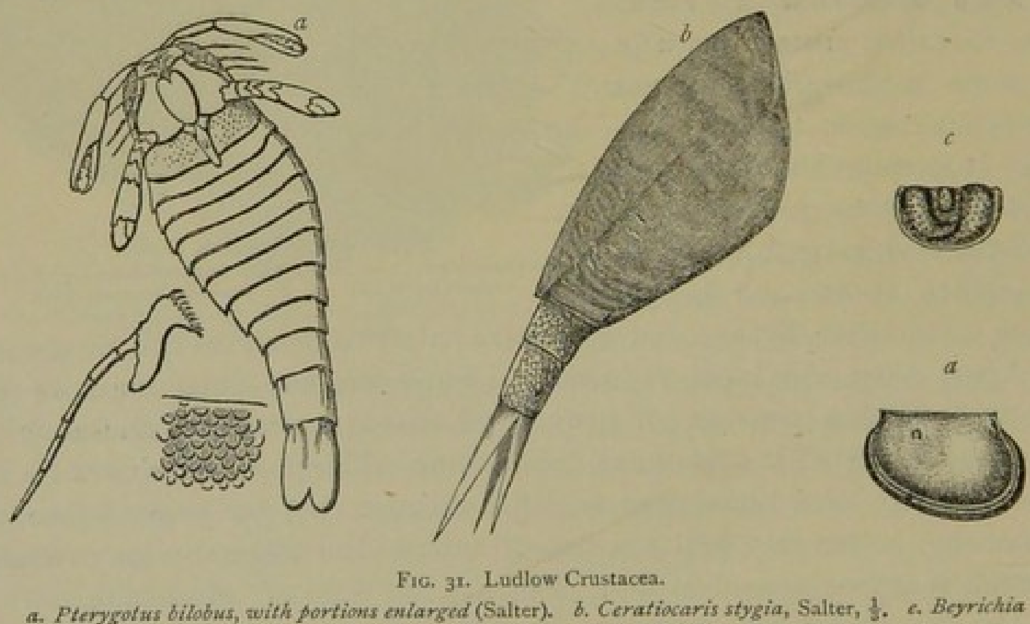
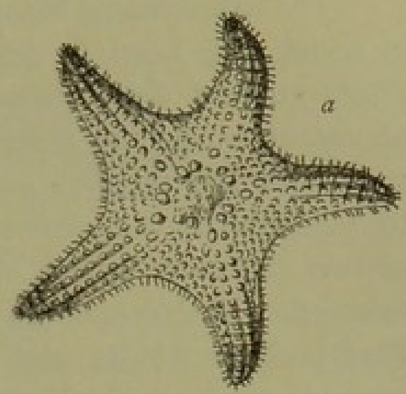


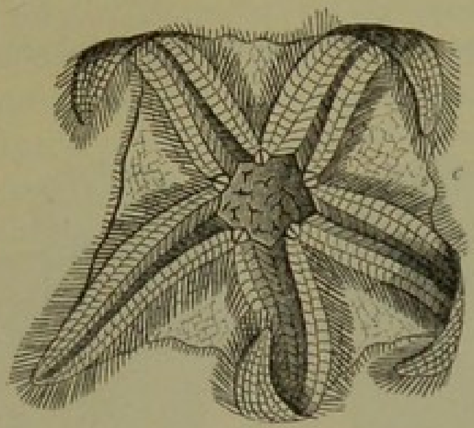
FIG. 31. Ludlow Crustacea.
a. Pterygotus bilobus, with portions enlarged (Salter). *b. Ceratiocaris stygia*, Salter, $\frac{1}{2}$. *c. Beyrichia Kloedeni*, McCoy, $\frac{4}{1}$. *d. Leperditia Balthica*, His., $\frac{1}{1}$.

quently found covering certain gasteropod shells, named in consequence *Cyclonema coralli*, Sby., and *Murchisonia coralli*, Sby.

Trilobites are also much scarcer. The *Calymene Blumenbachii*, and *Phacops caudatus* (Pl. II, fig. 5), still linger on; but the most common form is the indistinctly trilobed *Homalonotus* (*H. delphinocephalus*, Pl. II, fig. 7), of which two species, *H. Knightii*, König, and *H. Ludensis*, Murch., are peculiar to this group of strata, the former often attaining a very large size. But while there is a decrease in this order of Arthropoda, there is a large increase in the higher order of *Eurypteridæ*, of which the *Limulus* or King-crab of the present day is the representative. They are mostly peculiar to the Ludlow strata. One form, the *Pterygotus punctatus*, Salt., was gigantic, attaining apparently a length of 7 or 8 feet. Of the nebalioid Phyllopod *Ceratiocaris*, *C. papilio*, Salt., *C. stygia*, Salt., and *C. Murchisoni*, M^cCoy, were prominent forms. Entomostraca of the genera Beyrichia and Leperditia also frequently occur (Fig. 31).



Of Echinodermata there are some very characteristic Star-fishes, such as *Protaster Miltoni*, Salt., *Palæocoma Marstoni*, Salt., and *P. Colvini*, Salt.,—the last being peculiar to this group. Although Star-fishes appear in the Lower Silurian, it is not until we reach this upper division that the Asteroids, so common



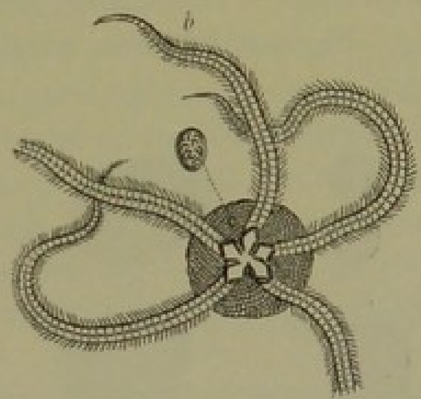


FIG. 32. Ludlow Asteroids.
a. Palæasterina primæva, Forbes. *b. Protaster Miltoni*, Salter. *c. Palæocoma Marstoni*, Salter.

in our present seas, become at all abundant. The Crinoids are few and the Cystideans gradually die out.

Among the characteristic Mollusca of the Ludlow rocks are,—

Pentamerus Knightii, *Sby.*	Bellerophon expansus, *Sby.* (Pl. V, fig. 3).
Orthis elegantula, *Dalm.*	Pterinea Danbyi, *M^cCoy* (Pl. V, fig. 1).
Rhynchonella Wilsoni, *Sby.*	Loxonema sinuosa, *Sby.*
Cardiola interrupta, *Sby.*	Orthoceras Ludense, *Sby.*
Leptæna lævigata, *Sby.*	Lituites giganteus, *Sby.*
Strophomena euglypha, *Dalm.*	Phragmoceras pyriforme, *Sby.* (Pl. V, fig. 6).

The *Pentamerus Knightii* (Fig. 33, *a*) is peculiarly characteristic of Ludlow strata both in England and on the Continent.

But the most interesting Palæontological feature of the Ludlow period is the first appearance of Fishes, of which eleven species, belonging to as many as seven genera, have been met with. They occur both in the lower divisions and in the upper division—the Tilestones; but they are far more numerous in the higher division. They particularly characterise the 'bone-bed' at the base of the Downton Sandstone. This bed, generally only a few inches thick, is a mass of fragments of Fishes, Crustacea, with some Conodonts and shells; and, though so thin, it forms a well-marked horizon over a wide area.

The fish-remains belong chiefly to those peculiar Placo-ganoid Fishes, in which the head is defended by a shield or buckler, as in the genera *Pteraspis* and *Cephalaspis*, an order of fishes which becomes extremely abundant during the succeeding, or Devonian, period. (Fig. 38, p. 80.)

With the remains of the ganoid fishes are others, belonging probably to placoids of the provisional genera *Onchus* and *Sphagodus*, to which certain defensive spines and shagreen scales of the bone-bed have been referred. The former may have been a Cestraciont fish allied to the living Port-Jackson Shark, and the latter to the existing Dog-fishes. Annelid jaws are found in the Upper Ludlow shales. The characteristic Ostracod is *Beyrichia Wilckensiana*, Jones.

Besides Fucoids, which, as in some of the older strata, are here very

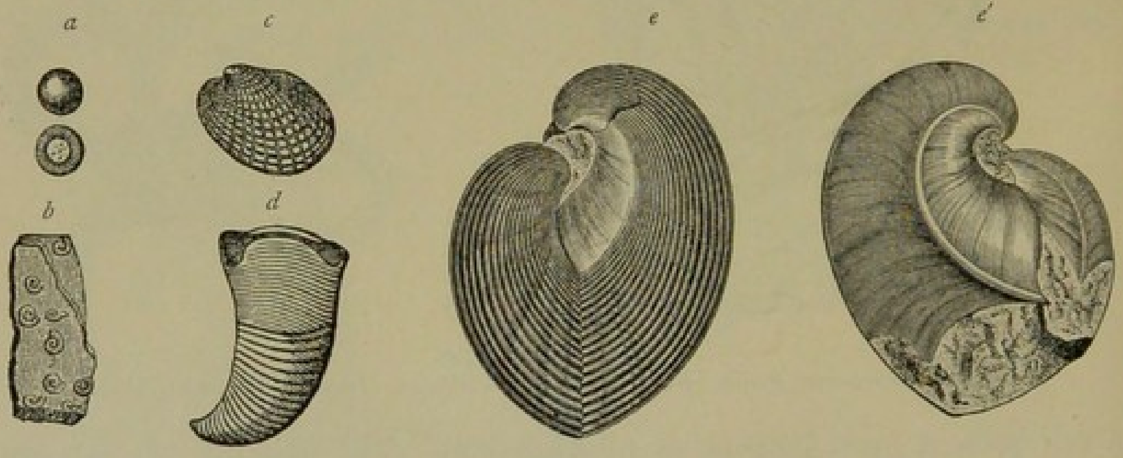


FIG. 33. Other Ludlow Fossils.
a. Pachytheca sphærica, Hook. *b. Spirorbis Lewisii*, Sby. *c. Cardiola interrupta*, Sby. *d. Phragmoceras ventricosum*, Sby. *e. Pentamerus Knightii*, Sby. *e'. Section showing septa.*

abundant in particular beds, it was in the Upper-Ludlow beds that the small globular seed-like bodies containing spores and referred by Sir Joseph Hooker to a Lycopodiaceous plant, termed provisionally *Pachytheca*, were first found.

In the upper or passage beds there is a singular falling off from the rich fauna of the other divisions of the Ludlow group.

The Silurian Strata of other parts of Great Britain. The variations in the characters of the Silurian series are so considerable that even within the limits of England and Scotland the exact correlation of the several groups yet presents difficulties.

In the Lake districts the strata have been much more disturbed and metamorphosed than in the Border Counties of England and Wales, and the limestone masses are fewer and the fossils not so well preserved. The different divisions established for Cumberland by the researches of Sedgwick, Harkness, and the officers of the Geological Survey are as under:—

The Border Counties of Wales.		*Cumberland.*
Upper-Ludlow Beds.	=	Kirkby-Moor Flags.
Lower-Ludlow and Wenlock.	=	The Bannisdale Flags, Slates and Sandstones.
Woolhope Limestone and Denbighshire Grits.	=	Coniston Grits and Flags.
Tarannon Shales and May-Hill Sandstone.	=	Stockdale Slates, Shales, and Conglomerates.
Caradoc and Bala Beds.	=	Coniston Limestone and Shale.
Llandeilo and Arenig Beds.	=	Skiddaw Slates.

A remarkable feature in the Cumberland series is the enormous development of rocks of igneous origin. It was estimated by Mr. Clifton Ward that the volcanic products of the ancient Cumberland volcanoes, in early Silurian times, have a thickness of at least 12,000 feet[1].

The Volcanic series of Borrowdale consists of alternations of contemporaneous traps and volcanic ash and breccia, green slates (ash-beds) and porphyries, many thousand feet thick, without the intercalation of ordinary sedimentary material, except quite at the base. Mr. Ward thought it probable that the eruptions commenced beneath and among the waters of the Skiddaw-slate sea, but that, either by elevation or the partial filling-up of the shallow sea-bed, they soon became almost wholly sub-aerial.

One of the main centres of eruption was close to the present site of Keswick; and in the low craggy hill of 'Castle Head,' Mr. Ward saw the stump of an old Cumberland volcano, which once poured out its lava-sheets and scattered ashy material for many miles around. He considered that, though denudation has destroyed all the semblance of volcanic form, yet there remain, at a little distance from the old vent, the broken ends of beds of lava and ash (such as those of Wallow Crag) which were once continuous upwards to a point far above the present summit of Castle Head. Other centres may exist in other parts of the district; but that of Keswick was perhaps one of the chief, and around it occur the greatest number of lava-flows. This forms a very remarkable chapter in the history of these ancient rocks, although we cannot yet feel certain that the analogy with recent volcanoes is so clearly established as Mr. Ward believed.

In Cornwall the rocks of this age, which, with the slaty rocks of Devonian age, are locally known under the name of 'Killas,' have been much disturbed and are generally unfossiliferous, so that it has been difficult to make out their order of succession. Silurian strata, considered to be synchronous with the Upper-Caradoc strata of Wales, have been recognised around Mevagissey and at a few places in the interior.

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[1] 'Quart. Journ. Geol. Society,' vol. xxxi. pp. 405, 417.

Silurian rocks are largely developed in Scotland; but they are generally unfossiliferous, except in the South, where also their order of succession has been best established. Rocks of Llandeilo, Caradoc, and Llandovery age, together with representatives of the Wenlock and Ludlow strata, form a wide belt ranging from the coast of Dumfriesshire and Ayrshire to the east coast of Berwickshire. At the base of the series, shales, grits, and conglomerates prevail. These are succeeded in the upper part of the Lower Silurian by sandstones with lenticular bands of limestone; while the Upper-Silurian strata consist of grits and flags with very fissile shales, limestone bands, and mudstones.

These Silurian rocks contain many of the common Corals, Brachiopods, and Crustacea of the Welsh and Shropshire area. Besides these, fine and well-preserved specimens of *Slimonia*, *Stylonurus*, *Pterygotus*, and *Ceratiocaris* are of frequent occurrence in the black shales of Lesmahago, Lanarkshire. Another feature of the Scotch Silurians is the great profusion and multitude of species of Graptolites. They abound in the black Moffat shales, of Llandeilo age, and in the dark Lower-Palæozoic fissile shales and mudstones of Girvan in Ayrshire, a district of great interest[1], where the fossils, which have been described by Professor Nicholson and Mr. R. Etheridge, Junior, are both numerous and better preserved than elsewhere in Scotland[2].

Some of the highly metamorphosed rocks of the Scottish Highlands are supposed to be of Lower-Silurian age; but, as they are unfossiliferous and affected by powerful folds and complicated inversions, which render their exact order of superposition difficult to unravel, some uncertainty still exists respecting their age.

Ireland[3]. The Cambrian rocks of Howth and Wicklow are overlaid unconformably by Lower-Silurian strata. The Arenig group, as well as the Upper-Cambrian division, are wanting. Strata of Llandeilo and Caradoc age are however largely developed, and form the mountainous districts of Galway, Mayo, Donegal, and Derry. They consist of schistose rocks, quartzites, and crystalline metamorphic rocks with few fossils.

The Lower-Silurian strata, like those in Wales, contain extensive sheets of felspathic trap, ashes, and agglomerates, ejected from submarine volcanoes, during the deposition of the sedimentary strata. In the South and East of Ireland, those strata have undergone less change, and are more fossiliferous, some of the dark schists there abounding, as in Scotland, with Graptolites. The Upper-Silurian strata occur only in a few localities, and represent probably the whole of that division; but, as in Scotland, they do not admit of the minor subdivisions established in the Border Counties of

[1] Lapworth, 'Quart. Journ. Geol. Soc.,' vol. xxxviii. p. 537.
[2] A Monograph of the Silurian Fossils of the Girvan District, 1878–80.
[3] See Hull's 'Physical Geology of Ireland,' pp. 9–26; and Kinahan's 'Geology of Ireland,' § 111.

England, although they are often highly fossiliferous. The break between the Upper and Lower Silurian is more marked than in England; and the basement-beds of the former generally consist of masses of fossiliferous grits and shales, and of conglomerates formed from the waste of the older metamorphosed Lower Silurians.

In parts of the north of Ireland[1], where the Lower-Silurian rocks have been less metamorphosed, they are rich in organic remains, especially in Trilobites. In the south, Upper-Silurian strata form part of the Dingle promontory, and the coast-section exhibits a highly fossiliferous series of shales, grits, and limestones.

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[1] Portlock's 'Report on the Geology of Londonderry' is a standard work on the fossils and stratigraphy of that district.

CHAPTER V.

THE SILURIAN ROCKS OF EUROPE AND OTHER PARTS OF THE WORLD.

France; no Upper Silurian. Belgium. Spain. Bohemia; Barrande's Divisions; Abundance of Fossils. Scandinavia. Russia; Ungulite-Grit. North America. Canada. Classification. Distribution and Range of Fossils. Mineral Oil. Salt. Identical Fossils. Arctic America. South America. Australia. China. Siberia. Gold. Its Distribution elsewhere. Yield of Gold.

France. The Silurian strata of France are, as a rule, more metamorphosed, disturbed, and faulted than those of England. The Palæontological researches of Marie-Rouault[1] and others, and the memoirs of MM. de Tromelin, Lebesconte[2], and Barrois[3] have, however, established in western France a definite order, which shows a close agreement with our Lower-Silurian series; but the upper series seems to be incomplete, if not absent.

There is a considerable development of the Lower-Silurian strata in Normandy; and it is still larger in Brittany. The Cambrian schists of Rennes are overlaid by the 'Grès Armoricain,' which consists chiefly of light-coloured quartzites, and contains but few fossils. Amongst these the long cylindrical tubes of *Cruziana* and *Tigillites* (*T. Dufresnoyi*) are conspicuous, the latter passing through the strata at right angles to the planes of stratification. *Oldhamia* and *Arenicolites* also occur. M. Lebesconte places these beds at the base of the Silurian. It is, however, a question whether they may not belong to the Upper Cambrian; for there is no definite line between the 'Schistes de Rennes' and the 'Grès Armoricain;' and they seem to pass one into the other. A passage seems also to exist between the Armorican beds and the overlying slates of Laillé and Angers, the Llandeilo age of which is well-established. Amongst the characteristic fossils of these slates are *Calymene Tristani, Ogygia Desmaresti, Olenus giganteus* (very large specimens of this species are found), *Didymograptus Murchisonii*, etc. These pass up into the 'Grès de May' with *Trinucleus Goldfussi, Orthis Budleighensis, Pseudarca typa, Diplograptus Baylei*, etc. To these succeed a series of carbonaceous schists, limestones, and sandstones (*schistes et calcaires ampéliteux*) with *Orthoceras subannulare, Cardiola interrupta, Monograptus priodon*, etc., which are probably the

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1 'Bull. Soc. Géol. France,' 2nd ser., vol. vii. pp. 370, 724; vol. viii. p. 358, and others.

2 *Ibid.*, 3rd ser., vol. iv. p. 583; vol. x. p. 68.

3 'Ann. Soc. Géol. du Nord,' vol. iv. p. 38; vol. vii. p. 259, and others.

equivalent of the May-Hill Sandstone: while the overlying white and somewhat chalky limestone of Erbray (Haute Loire), containing *Calymene Blumenbachii*, *Phacops fœcundus*, *Harpes venulosa*, etc., is probably synchronous with the Wenlock group.

In Belgium, M. Dewalque has shown the close relation between the Cambrian rocks of Wales and those of the Systèmes Salmien, Revenien, and Devilien, with *Oldhamia radiata* and *Dictyonema sociale*, of the Ardennes[1]. These are succeeded by the quartzites, carbonaceous flags, and porphyritic rocks of Blanmont, Oisquercq, and Gembloux, the Lower Silurian age of which has been established by Gosselet[2], Malaise[3], and others. These beds contain *Homalonotus Omalii*, *Lichas laxatus*, *Trinucleus seticornis*, *Illænus Bowmani*, *Orthoceras Belgicum*, *Orthis calligramma*, *Climacograptus scalaris*, etc.

The Silurian rocks of **Spain** have been described by De Verneuil[4], Casiano di Prado[5], and, more recently, by Dr. C. Barrois[6].

In Bohemia the Silurian series is largely developed; and its rich fauna has been exhaustively described by M. Barrande, who grouped the strata into zones in accordance with the character of their organic remains. These zones he subdivided into stages (étages). The zone in which he found the first traces of life[7] is his 'Primordial Fauna,' zone *C*. This, which consists of argillaceous schists, corresponds with the Cambrian series of England. Zone *D*, which commences with unfossiliferous conglomerates, and is succeeded by quartzites and a long series of schistose rocks, contains his 'Second Fauna,' and, as a whole, corresponds with our Lower Silurian series.

This is succeeded by slates with contemporaneous igneous rocks, and by three groups of limestones, overlain by schistose rocks—forming the stages *E*, *F*, *G*, *H*. The fossils of this series—the equivalent of our Upper-Silurian series—represent M. Barrande's 'Third Fauna.' He grouped them thus broadly, being unable to establish any closer correlation with the English subdivisions.

M. Barrande has described 2800 species of organic remains from the Silurian basin of Bohemia. In his 'Primordial zone (*C*),' Trilobites represent nearly the entire fauna, and no Cephalopods have been met with. In Stage *D*, Cephalopods and Graptolites were largely dominant; while he considered Stage *E* to have been the period of maximum development of Trilobites.

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[1] 'Bull. Acad. Roy. Belgique,' xxxvii. p. 596.
[2] 'Bull. Soc. Géol. France,' 2nd ser., vol. xvii. p. 495.
[3] 'Mém. Acad. Roy. Belgique,' xxxvii, and various other papers on the Silurian rocks.
[4] 'Bull. Soc. Géol. France,' 2nd ser., vol. xii. p. 964, and xvii. p. 526.
[5] *Ibid.*, vol. xi. p. 330, and xii. p. 182.
[6] 'Terrains Anciens des Asturies et de la Galice,' 1882.
[7] The two underlying zones, *A* and *B*, being void of life, were termed 'Azoic Zones.' They may correspond with our Pre-Cambrian Rocks; or *B* may represent some of the lower unfossiliferous Longmynd rocks.

According to M. Barrande, the total number of Silurian fossils known and described from Silurian strata in Europe and America amounts to 10,074 species. The divisions of the Silurian (and Cambrian) rocks of Bohemia[1] correspond as under with the British series :—

Étage H	Faune 3^{me},	Upper Silurian.	*h* 1, 2	= Passage beds, Ludlow, Wenlock and Llandovery rocks.
„ G			*g* 1, 2, 3, 4	
„ F			*f* 1, 2	
„ E			*e* 1, 2	
„ D	Faune 2nde,	Lower Silurian.	*d* 1, 2, 3, 4, 5	= Caradoc and Llandeilo.
„ C	Faune Primordiale	Cambrian.	*c* 1	= Lingula-flags and Menevian.
„ B	Étage Azoique			= Pre-Cambrian.
„ A	„ Azoique	Laurentian.		

Scandinavia. Of the Silurian rocks of Scandinavia, Murchison says—' There is nowhere to be seen the same concentrated succession of all the strata from their base upwards, or one natural section so clearly connecting the Upper and Lower Silurian, as is exhibited in Norway, and particularly in the territory of Christiania' ('Siluria,' 3rd edit., p. 367). But whereas the British series has a thickness of above 20,000 feet, the succession of strata representing this lengthened period in Norway does not exceed 2000 feet in thickness[2].

In the Islands of Gothland and Oesel the Silurian strata are particularly rich in fossils. In these Scandinavian rocks, Hisinger, Angelin, Lindström, Kjerulf, and others have recognised numerous Upper Silurian Corals (*Favosites Gothlandica, Omphyma turbinatum*, etc.), Entomostraca (*Leperditia Balthica, Beyrichia tuberculata*), etc.; and, in Oesel, Fr. Schmidt has found remains of Pterygotus and allied forms. Eichwald, Pander, and others have also described a large number of Upper-Silurian fossils from the Baltic Provinces of Livonia and Esthonia.

Other beds contain characteristic fossils of the Caradoc and Mayhill groups, amongst others the common *Pentamerus oblongus*. These are succeeded by a limestone containing many characteristic Wenlock fossils, such as *Rhynchonella borealis, Orthoceras annulatum* (Pl. V, fig. 7), etc.; higher in the series, Lower-Ludlow but not Upper-Ludlow fossils are found.

In Northern Russia these ancient deposits are not, as they are generally elsewhere, crystalline and metamorphosed, but are represented, in the neighbourhood of St. Petersburg, by shales, and sands, as incoherent as those of Tertiary age around London, and with clays so plastic that they are used for modelling; so entirely have these Russian strata been exempted from the influence of pressure and metamorphic action.

In some sandstones, occurring in the upper part of this series, the little horny Brachiopod, *Obolus* or *Ungula*, is so abundant that the rock is named the '*Ungulite Grit*.' It was in some green sands associated with

[1] The reader should consult M. Barrande's various papers in the 'Bull. Soc. Géol. de France,' his great work on the 'Système Silurien au Centre de la Bohême,' and his several synoptical Memoirs.

[2] Some part even of this 2000 feet is now referred to the Cambrian series.

this grit that Pander discovered large numbers of those minute bodies, some not longer than the eyes of needles, which he termed *Conodonts*. They have been referred by some to Myxinoid Fishes, and Dr. Hinde has recognised among them some Annelid jaws. Ehrenberg has pointed out that many of the green grains in these sands, as is frequently the case in newer formations, are the glauconitic casts of Foraminifera of the genera *Textularia*, etc.

Proceeding further eastward, the strata are found to become more compact, and limestones more frequent. On the banks of the river Dneister fossils identical with those of our Lower- and Upper-Silurian strata have been discovered, such as *Syringopora bifurcata*, *Calymene Blumenbachii*, *Ceriopora granulosa*, and others; in all thirty-seven species.

In North America[1] rocks of the Silurian and older periods occupy districts larger than the whole of Europe. They form a central area, round which the newer formations wrap. The region of the Great Lakes, of the northern tributaries of the Mississippi, and of the valley of the St. Lawrence, mainly consist of Laurentian, Huronian, and Silurian strata.

If a correlation with the British subdivisions cannot be extended to the Continent of Europe, much less can it be attempted in detail for the Continent of America. Nevertheless, it is remarkable that the two great divisions of an Upper- and a Lower-Silurian system are perfectly well defined, corresponding as a whole to the upper and lower divisions of the Silurian strata of Europe.

These strata have been grouped by American geologists in the following divisions:—

Oriskany Period	Oriskany Epoch	Upper	Silurian.
Lower Helderberg Period	Lower Helderberg Epoch		
Salina Period	Saliferous Epoch		
Niagara Period	Niagara Epoch		
	Clinton Epoch		
	Medina Epoch		
	Oneida Epoch		
Trenton Period	Cincinnati Epoch	Lower	
	Utica Epoch		
	Trenton Epoch		
Canadian Period	Chazy Epoch		
	Quebec Epoch		
	Calciferous Epoch		
Primordial (or Cambrian) Period	Potsdam[2] Epoch		
	Acadian Epoch		

[1] See the full and elaborate Reports of the Geological Surveys in the several States and Canada; also Professor Dana's 'Manual of Geology.' Bigsby's 'Thesaurus Siluricus' gives very valuable lists of all the known species of the Flora and Fauna of the Silurian period and of their distribution in Europe and America and other parts of the world. A more special work is Miller's 'Catalogue of the Palæozoic Fossils of North America.'

[2] Dana includes the Potsdam and Acadian divisions in his 'Lower Silurian;' they correspond however with the 'Primordial zone' of Barrande and the Cambrian series of this country.

The marked analogy of the conditions under which these early rocks were accumulated in Europe and in America, as shown by a general community of fossils, and by the prevalence of certain special genera in areas so distant, induces me to enter into some further details respecting this conspicuous series of American rocks, the thickness of which varies from 1,000 to 15,000 feet or more.

Of the Lower-Silurian strata Dana remarks, 'While the rocks of the Primordial [Acadian and Potsdam] period, over the larger part of North America, are chiefly sandstones and, but sparingly, limestones, and bear evidence in most places of shallow waters and of currents bearing sediments,—those of this second period of the Lower Silurian are as prominently limestones, and over large regions are indicative of clear seas. But, while limestones are the prevailing rock, all regions over the continent were not contemporaneously making limestones' (p. 192).

The limestones of New York may have resulted from the trituration of shells, crinoids, etc., the species being such as must have lived in comparatively shallow water, like those on the shell-banks and coral-reefs of the Pacific, where they are broken by the action of waves and currents, which at great depths are too feeble for such work.

The magnesian limestones of the Mississippi basin, which contain, on the contrary, very few visible fossils, are apparently, in a great part, made up of microscopic shells of Rhizopods, and therefore accumulated in deep water.

The Canadian series is remarkable for its copper-mines, those of Lake Superior being amongst the most productive in the world. The copper is mostly in its native state. One mass of pure copper was forty feet long, and was estimated to weigh 200 tons[1]. Some of the copper contains silver in a pure state in imbedded grains; sometimes the quantity is such that the copper is spotted white with it.

In the rocks of the Trenton period, which next succeed, occurs the Galena limestone of Wisconsin and adjacent States, so noted for its lead-ores, which occupy large cavities rather than veins, in the limestones. In the shales of these rocks mineral oil also begins to show, generally in small quantities, but sometimes rather abundantly.

The life of this period presents the same general characters as in Europe, but the changes are even more marked. Dana observes that at the close of the Primordial [Cambrian] period there seems to have been in the American area 'a general extermination of species, for no species of this epoch have yet been found in the higher [Silurian] rocks. No Trilobites of the Primordial period extend, so far as is known, into the beds of the next period;' and the genus *Paradoxides* disappears altogether, and becomes

[1] Another mass has since been found estimated at 500 tons.

extinct as in Europe. As a rule, however, the genera are continued, but represented by new species.

The plants, with the few exceptions before mentioned, are all marine, and the animals are all marine invertebrata. The lowest forms of animal life are represented by Rhizopods and Sponges. The *Stromatopora*, though closely resembling the massive corals, has been considered by some to be a *Rhizopod* related to Eozoon, and by others a sponge related to the Hydractinids. It forms irregularly hemispherical masses, often of very considerable size.

Another curious fossil of Spongid affinity is the *Receptaculites*, which Salter regarded as a Foraminifer allied to *Orbitolites*; Gümbel also considered it to be a true Rhizopod. Mr. Billings of the Canadian Survey placed it among Sponges, but with relations to the Foraminifera; its curiously symmetrical form is very striking. Dr. Hinde shows it to be a sponge[1]. Another gigantic form of sponge occurs—the *Archæocyathus*,—some specimens of which attained a length of from two to three feet.

Graptolites,—a few rare forms first appear in the Potsdam Sandstone. They become very numerous in strata of the 'Canadian' series. In the Quebec group alone, above fifty species have been found; they are, as in Europe, amongst the most characteristic fossils of the Lower-Silurian times. Dr. H. A. Nicholson[2] states that of the thirty-one species of Graptolites of the Skiddaw Slates, fourteen are species which Hall has described from the Quebec group of Canada.

No Corals have been found in the strata of the 'Canadian' period. They make their first appearance in the Trenton beds; but they are there scarce, as compared with those of the later Silurian periods. One genus, however, the *Columnaria*, attains a great development, some masses of it weighing between 2,000 and 3,000 lbs.

Crinoids in general are not common, but that peculiar extinct order—the *Cystoidea*—abounds, and is represented by as many as 22 species.

Amongst Molluscs, univalves are rather common, whereas bivalves are comparatively scarce. *Pteropoda* are very numerous, and much larger than any living species of this order. *Cephalopoda* appear first in the straight form of *Orthoceras*. They are very numerous in the Trenton rocks, where some of them attain the gigantic size of from 10 to 15 feet in length. In the upper beds the curved forms make their first appearance.

Brachiopoda, however, were the characteristic shells of the American Palæozoic seas. Dana says that they exceed any other order by a hundredfold. *Orthis* is particularly abundant. The genus *Rhynchonella* first makes its appearance in the Quebec group. *Leptæna* and *Strophomena* appear in the Calciferous epoch.

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[1] 'Quart. Journ. Geol. Soc.,' vol. xl. p. 827. [2] *Ibid.* vol. xxviii. p. 217.

Above 100 species of *Trilobites* of the 'Canadian' period have been described. There are no *Paradoxides*, but species of *Bathyurus*, *Dikelocephalus*, *Agnostus*, *Olenus*,—genera that began in the Primordial period,—together with species of *Asaphus*, *Illænus*, and other genera, which became prominent in the succeeding period, are numerous. It is to be noted that only one species of Trilobite of the Quebec series passes up into the Trenton, and even this is doubtful.

Another group of Crustaceans,—the minute *Ostracoda*,—which first make their appearance in the Potsdam Sandstone, swarm in this succeeding period; and, whereas the living species are generally about the size of a pin's head, those of the Silurian rocks are sometimes five or ten times that size.

Dana expresses an opinion that the American Continent was already outlined at this early geological period,—that its coming features, its wide interior basins and great lakes, were shadowed forth, although its mountains had yet risen but little above the sea.

The Upper-Silurian strata form a series of about 6,000 feet thick. The lowest member of the Niagara group is a pebbly sandstone or conglomerate, which is succeeded by thick sandstones, and then by limestones, shales, and massive sandstones, having a wider range than the lower beds. In these a few lead- and copper-mines are worked, and iron-ore occurs; but metallic veins are far less numerous than in the Lower Silurian. Mineral oil also occurs in the Niagara 'limestone of Chicago; and, although not in quantities sufficiently large to be worked to advantage, a portion of the limestone is completely saturated with oil.' While it is in the Devonian rocks that the great oil-works are seated, this singular product, which is certainly in many cases derived from the destruction of animal matter, seems in North America to pervade more or less almost the whole of the Palæozoic series.

Further, whereas in England our great salt deposits are all in beds of Triassic age, in America important deposits occur in the Salina beds of the Upper-Silurian series ('Onondaga Salt-group'). In the State of New York the salt is made from a strong brine[1] obtained by sinking wells varying from 150 to 340 feet in depth. In Canada rock-salt is worked in beds from 14 to 40 feet thick, and at a depth of about 1,000 feet. In all these salt-bearing strata gypsum occurs, as in England, in interbedded masses.

The Upper-Silurian strata of the United States abound in fossils. Many new forms of Corals and Crinoids come in. The Chain-coral (*Halysites*) ends here; but *Favosites* and the *Cyathophyllidæ* increase in numbers.

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[1] It takes from thirty-five to forty-five gallons of this water to make a bushel of salt; whereas it takes 350 gallons of sea-water for the same result. (Dana.)

Graptolites had their maximum development in the Lower-Silurian series. In the Upper series only a few species survive. Amongst Annelids *Tentaculites* abound, and attain their maximum development.

Brachiopods of the genera Spirifer, Athyris, and Chonetes make their first appearance. As in the British strata, Lamellibranchs and Gasteropods are few; the former being mainly represented by species of the genera *Avicula*, *Arca*, *Mytilus*, and *Cardium*; while the latter belong to the *Turbinidæ*.

The *Orthocerata* are neither so large nor so numerous as in the Lower Silurian. On the other hand *Conulariæ* are larger and more numerous, and *Bellerophon* is common.

The older genera of Trilobites—*Calymene*, *Agnostus*, *Asaphus*, *Illænus*, etc.—are continued, and new genera—*Phacops* and *Homalonotus*—appear. Of the other Crustacea, *Eurypterus* and *Pterygotus* are also new; the small Ostracoda continue common.

Professor Claypole has recently discovered fish remains (*Onchus* and Palæaspis) in the Clinton strata (= Upper Ludlow) of Pennsylvania.

Dana estimates that the number of described Upper-Silurian fossils amounts to about 3,500, of which thirty-nine are identical with species found in England. Amongst these are *Atrypa reticularis*, *Orthis elegantula*, *Pentamerus oblongus*, *Rhynchonella cuneata*, *Spirifer crispus*, *Strophomena rhomboidalis*, *Orthoceras annulatum*, *O. undulatum*, *Calymene Blumenbachii*, *Homalonotus delphinocephalus*, *Halysites catenulatus*, etc. (see Table II).

Arctic America. Silurian rocks have been found at the most extreme points of Arctic North America hitherto reached. Upper-Silurian strata occur on the shores of Smith's Sound and Barrow's Strait, and they form most of the Parry Islands and Boothia. With a great number of species peculiar probably to that region, there are associated others of common European types, such as *Halysites catenulatus* (Chain-coral), *Favosites Gothlandica*, *Atrypa reticularis*, *Pentamerus conchidium*, and *Rhynchonella cuneata*, while American-States species of the same age have been recognised on the shores of Kennedy Channel.

In **South America** the great axis of the Andes is formed, in main part, of highly metamorphosed Silurian rocks, containing fossils of the same genera as in Europe, such as '*Graptolites*, *Lingulidæ*, *Orthidæ*, and Trilobites of the genera *Asaphus* and *Phacops*' (D. Forbes).

In **Australia** there is a considerable development of Palæozoic rocks; amongst them are Silurian Strata, recognisable by their *Trilobites*, *Graptolites*, and *Lingulellæ* of the same general characters as those of Europe. According to Dr. Bigsby, sixty European genera have been discovered in the Silurian rocks of South Australia; and Professor McCoy states that in Western Australia there are one *Brachiopod*, one *Trilobite*, and eighteen *Graptolites* of species identical with those of Europe and America.

It is in the highly metamorphosed Silurian rocks of Australia that auriferous quartz-veins so frequently occur. The veins traverse the rocks irregularly, and their precise age does not seem to be known[1].

Asia. The Geological Survey of India has determined the presence of Lower-Silurian rocks in the Salt Range and the Simla area; while in the great chain of the Himalayas, Silurian rocks, flanked by Secondary formations, form part of the central axis of the range[2]. In China, Silurian Graptolites and Orthoceratites have been met with.

Similar formations spread over large tracts in Southern Siberia, in the Altai mountains, and in Asia Minor. In these regions they generally consist of hard crystalline and schistose rocks, associated, in the great mountain-chains, with erupted porphyries and greenstones, in strong contrast to the soft and slightly coherent Silurian rocks which spread throughout Russia in Europe. In this latter area, no mineral veins exist, and there is a total absence of crystalline rocks, whether of intrusive or metamorphic character. Sir R. Murchison remarks that where thrown up into inclined and broken positions in the Ural chain of mountains, and pierced by porphyry, greenstone, syenite, and granite, in association with huge masses of serpentine, the very same deposits that are so soft in European Russia have been hardened, crystallised, veined, and rendered highly metalliferous. In these masses so altered, auriferous veins are found, as in Australia, and the débris of these veins occurs in the drift scattered over the bottom of the adjacent valleys.

Occurrence of Gold. While upon this subject, a few more words may be said upon the occurrence of gold in Palæozoic rocks elsewhere. It occurs, as before mentioned (Vol. I, p. 322), *in situ* in the Lower-Silurian rocks of Wales, and has been met with in small quantities in Cornwall and Devonshire. In Scotland, gold has been found in the older crystalline rocks of the northern Highlands, and also in the slates of the South of Scotland[3]. In Ireland, gold has been carried down by the mountain streams from the altered Lower-Silurian schists of Wicklow. In Bohemia, again, gold was formerly extracted from veins in the Silurian strata.

In India, gold occurs in quartz-reefs traversing the metamorphic rocks, as well as independently in quartzites and schists. Mr. Ball further mentions that *detrital* gold has been found not only in some of the rocks of

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[1] It was formerly supposed that gold was confined to rocks of Silurian age, and to the débris derived from them. But now, although a large portion of the auriferous quartz-veins of the world occur in Silurian strata, it is found that such veins are by no means restricted to rocks of this age, and that they exist in metamorphosed rocks of various periods, both of the Palæozoic and Mesozoic age, and even as late as the Cretaceous; and it has been shown that the rich auriferous quartz-veins of California are situated in rocks of Triassic and Jurassic age.

[2] Medlicott and Blanford's 'Geology of India.'

[3] 'Siluria,' p. 451.

the Gondwana system in Peninsular India, but also in Tertiary rocks flanking the whole length of the Himalayas[1]. In Brazil it occurs in a chain of mountains of old rocks which run nearly parallel with the coast. In Chili, Peru, and Mexico, it is sparingly distributed, whilst silver is abundant.

There are mines in Africa between Darfour and Abyssinia ; also in the district between Senegal and Cape Palmas on the Guinea coast ; and along that part of the African mainland opposite Madagascar, which lies between 15 and 28 degrees of South latitude. The region of Ophir is supposed by some to have been on this coast, which includes the rich gold fields of the Kaap and others in the Transvaal. Gold is found also further south in Natal and parts of the Cape Colony. Gold, in fact, is widely distributed all over the world, especially in India ; but in a number of places (chiefly alluvial gravels) where it was formerly largely and profitably worked, it does not now pay the cost of extraction[2].

Gold is generally found associated with Platinum, Iridium, and Palladium, metals which, like it, are always found in a native state. Native gold usually contains silver in varying proportions, and occasionally copper. In 1872 'the total yield of the gold-mines of the world was not less than 195 tons (annually),—much the larger part of this, about 175 tons, coming from Asiatic Russia, South America, Australia, and California.' It was distributed as under :—

Russia	75,353	lbs. Troy.
Europe, exclusive of Russia	8,047	"
Africa	4,500[3]	"
South America	27,100	"
Mexico	10,000	"
Australia	250,000	"
California	200,000	"

The larger portion of the gold extracted from the Alluvial or Drift Beds is in the state of powder or small particles, though occasionally blocks or nuggets of considerable size are found. One of the largest masses yet discovered in any part of the world was in 'California ; it weighed 134 lbs. 7 oz., and was worth £5,532[4].'

[1] See Mr. Valentine Ball's account of the Gold of India in 'Manual of the Geology of India, Part iii, Economic Geology,' chapter iv.

[2] Although gold is so costly a metal it forms one of the cheapest materials for ornament on account of its extreme malleability, and not tarnishing on exposure. It can be beaten into leaves of extreme thinness, a single grain of the metal, worth less than twopence, may be thus made to cover about 57 square inches of surface, or a surface of 7 inches by 8. Perfectly pure gold is denominated gold of 24 carats, or 'fine gold' ; 22 parts of pure gold to 2 of alloy of copper or silver, is said to be '22 carats fine' ; and so on for 20, 18, or less proportions of gold. The ounce of 22 carat gold is worth £3 17*s*. 6*d*.

[3] Very greatly increased of late years. In eight months of 1886 South Africa exported £122,000 worth of gold.

[4] Dana, 'Mineralogy,' pp. 314, 319.

CHAPTER VI.

THE DEVONIAN SYSTEM: THE OLD RED SANDSTONE.

ITS DIVISIONS IN DEVONSHIRE. ORGANIC REMAINS. PLANTS. PROTOZOA. HYDROZOA. ACTINOZOA. FISHES. RED SANDSTONES OF THE COAST OF THE MORAY FRITH. EXTRAORDINARY FORMS OF SOME OF THE FISHES OF THIS PERIOD. OTHER FISHES ALLIED TO EXISTING FORMS. MOLLUSCA. DEVONIAN ROCKS OF IRELAND AND SCOTLAND. DEVONIAN ROCKS OF THE CONTINENT AND AMERICA. NORTHERN FRANCE AND BELGIUM. BELGIAN DIVISIONS. PASSAGE INTO CARBONIFEROUS STRATA. WESTERN FRANCE. GERMANY. THE EIFEL. RUSSIA. COMBINED DEVONSHIRE AND SCOTTISH TYPES. AMERICA. DIVISIONS. MINERAL OIL, ORIGIN OF. ORGANIC REMAINS. INSECTS. ABUNDANCE AND VARIETY OF THE VEGETATION. CANADA AND NEW BRUNSWICK.

THE Old Red Sandstone, as these strata were originally designated to distinguish them from the New Red Sandstone, consists, where first studied in Herefordshire, the Border Counties, and the North of England, of thick masses of red sandstones, clays, and conglomerates, with very few organic remains; but in the rocks of this period, and of similar petrological characters in Scotland, fish and plant remains are far more common. Coarse massive-jointed conglomerates, such as represented in Fig. 34, form a marked feature in the lower part of this series in Scotland

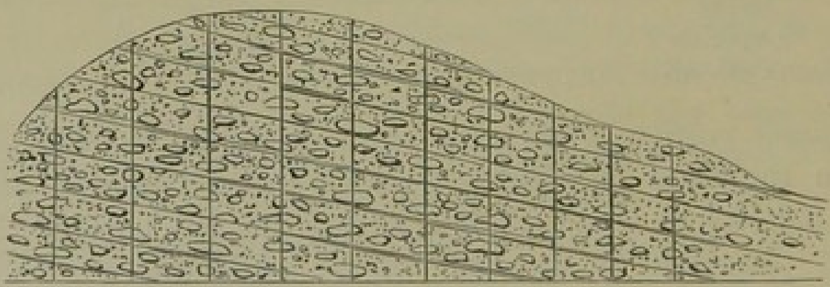

FIG. 34. *Vertical Joints cutting through a coarse conglomerate.*

and Ireland. Subsequently, Sedgwick and Murchison found in Devonshire a succession of strata consisting of fossiliferous slates with thin calcareous bands, thick coralline and shelly limestones, red schists, sandstones, and grits, occupying the same position as the Old Red Sandstones of Herefordshire and Shropshire, that is to say, between the Silurian and the Carboniferous Series; and to these, from their large development in that county, the name 'Devonian' was applied [1].

[1] An excellent account of the relations of the Old Red Sandstone and Devonians in Great Britain and Ireland and the Continent by the late Mr. J. W. Salter will be found in the 'Quart. Journ. Geol. Soc.,' vol. xix. p. 474, 1863.

These strata have there been divided into three groups, as under, in descending order:—

1. The Upper, or Barnstable, Pilton, and Marwood beds,	consisting of calcareous schists, light-coloured and compact red sandstone, and micaceous flags.
2. The Middle, or Ilfracombe and Combe-Martin beds,	consisting of red and grey sandstones, and glossy slates, with irregular bands of limestone.
3. The Lower, or Lynton beds,	consisting of hard, red, purple, and grey sandstones, schistose rocks, and a few thin conglomerates.

In South Devon the limestones of the Middle series are far more largely developed, and form the massive rocks so extensively worked at Plymouth and near Torquay for building and ornamental purposes. Certain beds full of corals, worked near Torquay, furnish some of the most beautiful of our British marbles.

There are thus two very distinct types of rocks belonging to this period; and it is probable that the calcareous schists, flags, and limestones of the South of England are the deeper-sea deposits of a series, of which the lower arenaceous and conglomerate beds, more fully developed as we proceed north, are the shallow-water or littoral deposits.

The palæontological characters of these southern and northern strata are not less distinct than are their petrological characters. Corals and shells abound in the former; fishes and plants constitute the most characteristic and almost the only fossils of the latter.

Organic Remains. We have had evidence in Cambrian and Silurian strata of the existence of a marine vegetation, but the evidence with respect to land plants is restricted to a few rare instances in the Upper-Silurian strata. In the Devonian period, however, a land Flora of considerable luxuriance makes its appearance. Among the plants are *Equisetaceæ* (horsetails), *Lycopodiaceæ* (clubmosses), and *Filices* (ferns), classes which became so largely expanded during the succeeding Carboniferous period. Amongst the more characteristic species are *Lepidodendron nothum*, Unger, *Psilophyton Dechenianum*, Carr., and *Sagenaria truncata*, Göpp.

It is now also that a class of trees which, at all subsequent geological periods as well as at the present, formed so important a part of the flora, viz. the *Coniferæ*, make their first appearance. They belong to the genera *Araucaryoxlon* and *Pinnularia*. The Devonian strata of Britain are however, compared with those of the Continent and America, poor in plants, having yielded only eighteen species.

The Old Red Sandstone of Scotland contains remains of *Calamites* and *Lepidodendron*, while *Zosterites* and some fucoid impressions abound in the flagstones of Forfarshire. In the yellow sandstones of the South of Ireland there are the remains of a luxuriant Fern Flora, including species of *Palæopteris*, *Pecopteris*, *Sphenopteris*, and others. The *Palæopteris Hibernica* was a magnificent plant, some of its fronds, perfectly preserved from the base to the extremity, being five feet in length. Specimens of *Knorria*, tree-like in size (over twenty feet in length), with the upper portion branching and again subdividing, are also found.

Protozoa. The number of Foraminifera and Sponges is small. Among the latter are species of the genera Sphærospongia, Ischadites, Scyphia, and the doubtful Stromatopora.

Hydrozoa. Graptolites, which so abounded in the Silurian period, have entirely died out.

Actinozoa. About fifty-five species of Corals are found in the Devonian strata; they are mostly of genera which occur also in the Silurian strata; but the species were shown by Mr. Lonsdale to be different. The group of *Cyathophyllidæ*—corals having a cup-like depression in the centre, and either simple or compound—are very abundant. The *Favositidæ* are also, as in the Silurian period, largely represented. One of the *Milleporidæ*

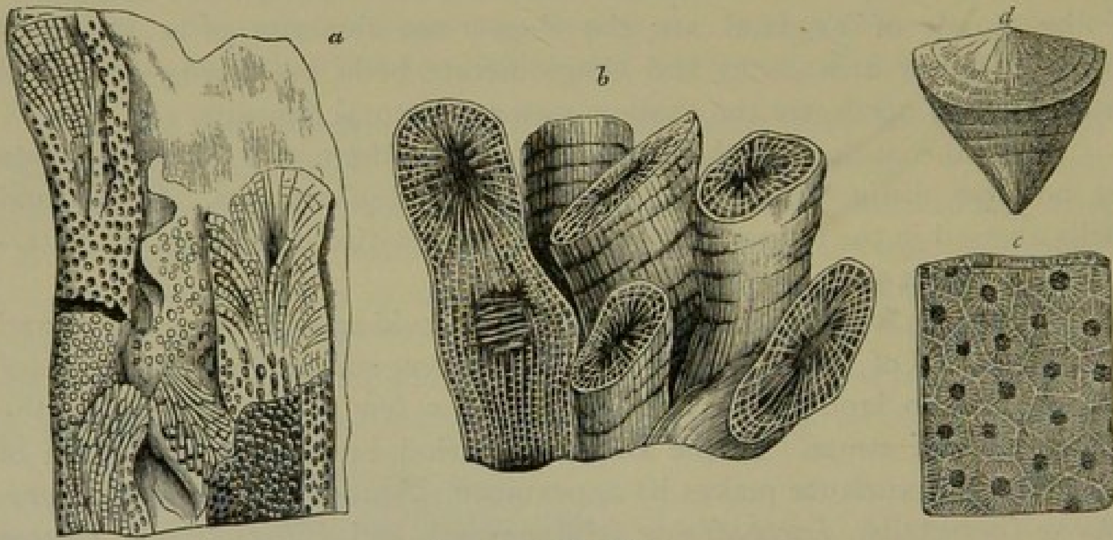

FIG. 35. Devonian Corals.
a. Favosites reticulata. b. Cyathophyllum cæspositum. c. Acervularia Goldfussi. d. Calceola sandalina.

(*Heliolites porosus*) is a characteristic Devonian fossil. A curious abnormal form of the coral, which is peculiar to Devonian strata, has a lid, or *operculum*, closing the mouth of the calice. In appearance it is more like a shell than a coral; and was, in fact, formerly supposed to be a Brachiopod; now it is regarded as an operculate rugose coral—the *Calceola sandalina.*

Both the Rugose and the Tabulate corals are well represented in the Devonian strata. Of the *Perforate* corals, on the contrary, only one genus occurs in these beds. Most of these corals belong to the group of deep-sea corals. The *Heliolites* and some others may, however, have been reef-builders. The characteristic species of the Devonian series, many of which are beautifully preserved in the Torquay limestones, and show, in polished specimens, the most minute details of their frame-work, are:—

Cyathophyllum cæspitosum, *Goldf.* Fig. 35 *b.*
Acervularia Goldfussi, *de Vern.* Fig. 35 *c.*
Favosites reticulata, *Blain.* Fig. 35 *a.*
Aulopora serpens, *Goldf.*
Petraia celtica, *Lonsd.*
Heliolites porosus, *Goldf.*

The **Echinodermata** are best represented by the *Crinoids*, of which the genera *Cupressocrinus*, *Haplocrinus*, and *Melocrinus* are peculiar to this period. Most of the other genera belong to families common to the Carboniferous period. The peculiar *Cystoidea* die out about the close of the Silurian period, and are succeeded by the equally peculiar *Blastoidea*,—one genus of which, the *Pentremitidea*, is very characteristic of the Devonian Series, to which it is confined, on the Continent and in America. Two starfishes are also known in the Devonian strata. Amongst the crinoids of this period are:—

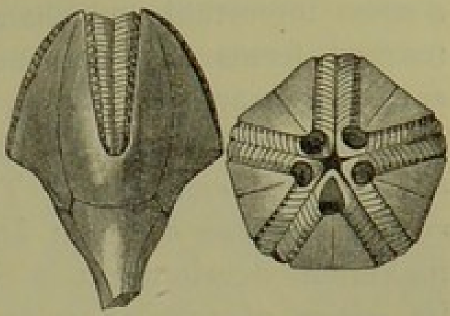

FIG. 35*.—*Pentremitidea clavata*, Schultze; The Eifel. (After Etheridge and Carpenter.)

Cupressocrinus crassus, *Goldf.*
Hexacrinus interscapularis, *Phil.*
Cyathocrinus macrodactylus, *Phil.*
Pentremitidea, sp.

Crustacea. Entomostraca are very abundant. *Estheria* in Caithness and *Entomis* in Germany extend over many square miles of strata. Trilobites so abundant during the preceding periods are now reduced to seven genera, of which Bronteus (*B. flabellifer*, Goldf.), Harpes (*H. macrocephalus*, Pl. II, fig. 12), Phacops (*P. latifrons*, Bronn, Pl. II, fig. 8), are the most characteristic.

On the other hand, the Merostomatous Eurypteridæ which made their appearance in Upper-Silurian times still continue their comparatively short-lived course, disappearing early in the Carboniferous period. The three prevailing genera are Eurypterus (*E. Scouleri*, Hib.), Pterygotus (*P. anglicus*, Ag.), and Stylonurus (*S. Scoticus*, Woodw.). The Isopods, which live both in fresh and salt water, and many of which are parasitic, make their first appearance in the *Præarcturus gigas*, Woodw., of the Old Red Sandstone of Herefordshire and Scotland.

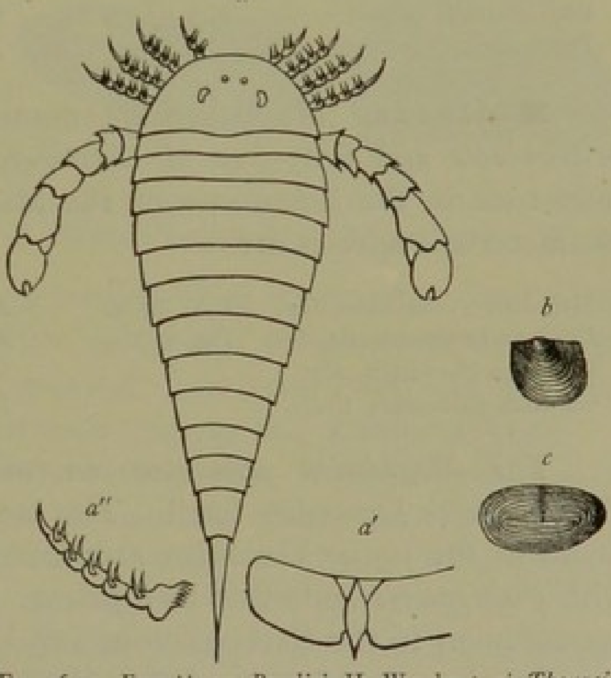

FIG. 36. *a. Eurypterus Brodiei*, H. Woodw.; *a'. Thoracic plate. a''. Endognath (maxilla)* enlarged. *b. Estheria membranacea*, Pachti, $\frac{4}{1}$. *c. Entomis serratostriata*, Sandb., $\frac{12}{1}$.

The Devonian Polyzoa show, like the Crinoids, closer relations with the Carboniferous than with the Silurian forms. All the genera except one pass up into the Carboniferous series, and several species, such as *Fenestella antiqua*, *F. prisca*, *Glauconome bipinnata*, *Polypora laxa*, and *Ptilopora flustriformis*, are common to the two periods.

Brachiopods still constitute in this, as in the Silurian series, a most important and characteristic group of fossils. Amongst the best marked forms are the broad-winged Spirifers; such as the *Spirifer macronotus*, and *Sp. disjunctus*. Other species peculiar to the Devonian period are the *Stringocephalus Burtini*, remarkable for its prominent beak, and *Atrypa desquamata*. The *Atrypa reticularis* and *Pentamerus brevirostris* are also common Devonian fossils, although they attained their maximum development in Silurian times; whilst the genus *Chonetes*, with its fringe of tubular spines on the ventral valve, commences in the Devonian and is prolonged into the Carboniferous period. The genus *Uncites*, one of the *Spiriferidæ* in which the shell is non-punctate and has no true hinge-area, is confined altogether to the Devonian period. In all there are one hundred and fourteen species of Devonian Brachiopods. The following are some of the most typical forms:—

Spirifer disjunctus, *Sby.* Pl. II, fig. 8.
Retzia ferita, *Von Buch.* Pl. IV, fig. 2.
Orthis interlineata, *Sby.* Pl. IV, fig. 6.
Rhynchonella cuboides, *Sby.* Fig. 37.
Pentamerus brevirostris, *Phil.*
Cyrtina heteroclita, *Defr.* Fig. 37.
Stringocephalus Burtini, *Defr.* Pl. IV, fig. 1.
Reusselæria stringiceps, *Röm.*
Chonetes Hardrensis, *Phil.* Pl. IV, fig. 5.
Atrypa desquamata. *Sby.*

Mollusca. Mr. Etheridge enumerates sixty-three species of *Lamellibranchiates* and forty-five of *Gasteropods*, the latter being by far most numerous in the limestones of the Middle Devonian. Among the most characteristic species are:—

Megalodon cucullatus, *Sby.* Pl. V, fig. 9.
Pterinea Damnoniensis, *Sby.* Fig. 37 *c.*
Cucullæa Hardingii, *Sby.*
Cardium palmatum, *Goldf.*
Aviculopecten transversus, *Sby.*
Anodonta Jukesii, *Forb.*
Murchisonia spinosa, *Phil.*
Euomphalus annulatus, *Phil.*

The *Megalodon* possesses enormous hinge-teeth, and is a very characteristic Devonian fossil. The large *Anodonta Jukesii* has only been found in the upper Devonian sandstones of Ireland, where it is associated with *Palæopteris* and other land-plants. Of *Lamellibranchiates* seven species are common to the Carboniferous and Devonian periods.

On the other hand, of the *Heteropoda*, of which there are only six species, as many as three continue up into the Carboniferous series. Of the four genera which existed in the Silurian period, only one, *Conularia*, survived through the Devonian; they are very distinct, and, though generally about the size of a thimble, some of them attained the length of a foot or more.

The important section of *Cephalopoda* is well represented by *Nautili*, *Orthocerata*, and the genus *Clymenia*,—the last being peculiar to the Devonian period, and especially characteristic of it on the Continent. *Goniatites* are few, not attaining their maximum until they reach the Carboniferous series. The genus *Orthoceras* is well developed. Altogether there are sixty species of *Cephalopods* in the Devonian strata of Britain, only a small percentage of which pass up into the Carboniferous series. Among the most common and characteristic species are:—

Clymenia undulata, *Münst.* Fig. 37 *d.*
Cyrtoceras nodosum, *Phil.*
Orthoceras cinctum, *Sby.*
Goniatites globosus, *Münst.* Plate V, fig. 11.

Fishes. In the massive Red Sandstones and Conglomerates, forming the bold cliffs of Banffshire, the beautiful scenery of the Findhorn, and the picturesque shores of Cromarty, are intercalated a few thin

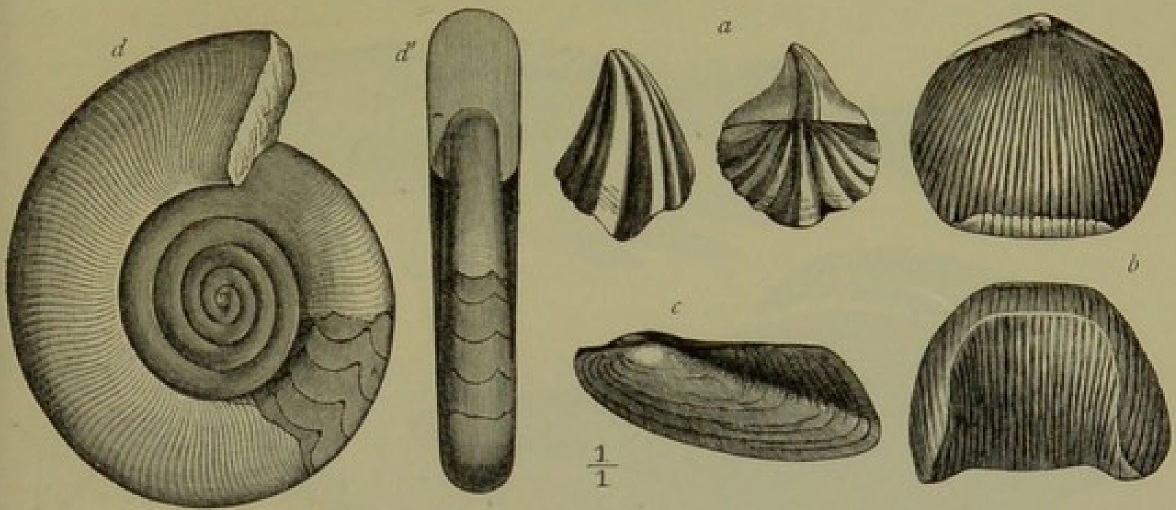

FIG. 37. Other Devonian Fossils.
a. Cyrtina heteroclita. b. Rhynchonella cuboides. c. Pterinea Damnonensis. d, d'. Clymenia undulata.

argillaceous beds, which at Gamrie, Lethen Bar, Cromarty, and some other places, contain layers of flattish calcareous nodules; these, when broken open in the plane of their greatest diameters, often disclose the impressions and the scales of fishes of most curious and peculiar types[1].

Of the six orders of fishes, two, namely, the *Elasmobranchii* and *Ganoidei*, were largely represented at this period. They made, as before mentioned, their first appearance toward the end of the Silurian period, but those fragmentary remains are confined to a few beds and to a few species. They now become common and well-preserved. Their forms are most extraordinary. Some of them are so very unlike fishes, that, until examined by Agassiz, they were referred to Crustaceans or other lower forms of life. They are characterised by having the head and generally the anterior portion of the body encased in an armour of numerous large plates, while the posterior extremity of the body is free and more or less unprotected. Though placed by Agassiz amongst

[1] The first collection of these remarkable fishes was made by Hugh Miller, while he was still a working mason at Cromarty. Many of them were described by Agassiz in his great work 'Poissons Fossiles.' A popular and most attractive account of them was afterwards given by Miller in 'The Old Red Sandstone of Scotland.'

the Ganoids, Professor Huxley has shown that *Coccosteus* and *Pterichthys* approximate in many respects to the *Silurioid Teleosteans*. Amongst the most characteristic of these Placo-ganoid Fishes are those represented in Fig. 38. The *Scaphaspis* (Pteraspis) *Lloydii* belongs to this group[1].

There are several species of *Cephalaspis*, which is so named from the large shield covering the head. The *Coccosteus* has also a similar shield, and its mouth was furnished with a lower jaw or mandible, carrying small teeth. In *Pterichthys* (winged fish) the pectoral fins are in the shape of two long curved paddles, covered by finely-tuberculated ganoid plates.

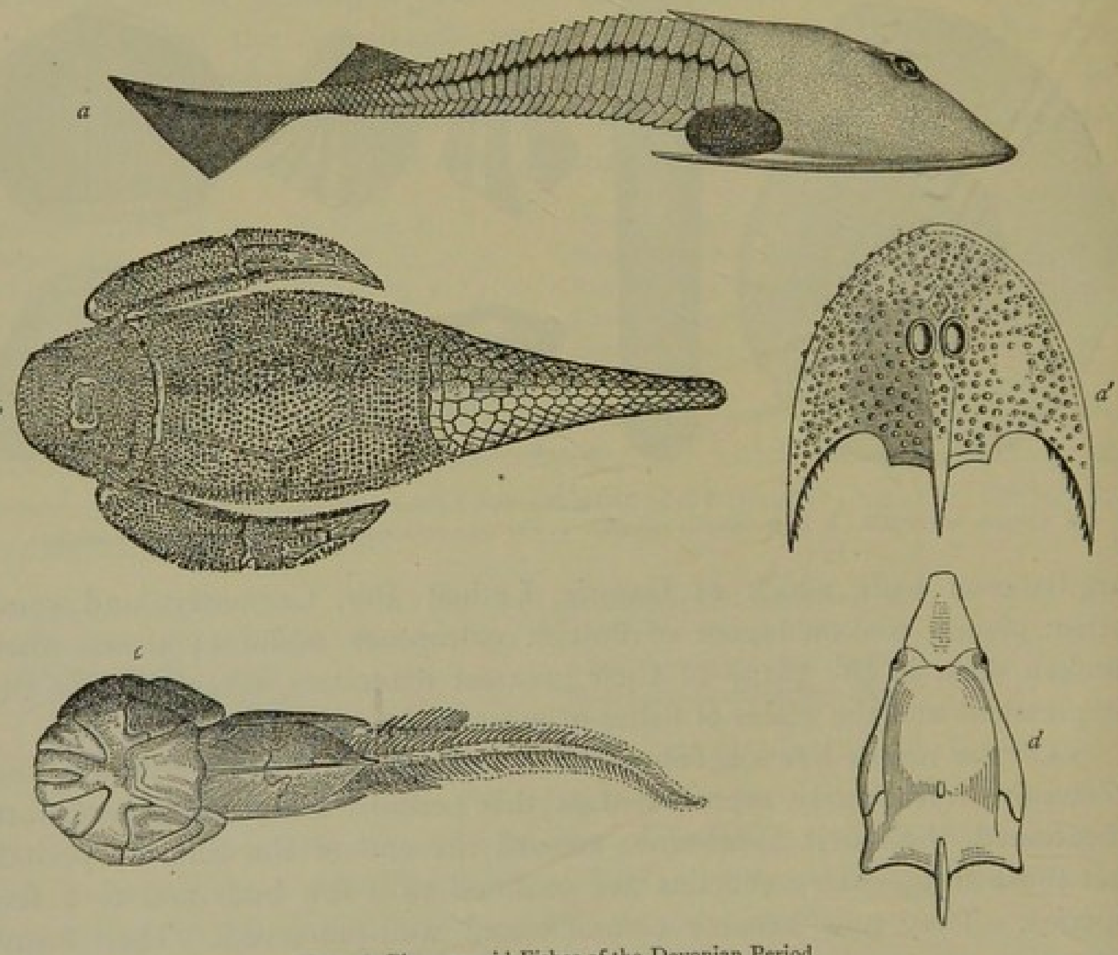

FIG. 38. Placo-ganoid Fishes of the Devonian Period.
a. Restoration of Cephalaspis (after Ray Lankester). *a′. Shield of Cephalaspis* (after Ray Lankester). *b. Pterichthys cornutus*, Ag. *c. Coccosteus decipiens*, Ag. *d. Shield of Pteraspis* (after Ray Lankester).

The singularity of form, the armour-plated head and fore-body, the unprotected end of trunk, and the absence or insignificance of fins, suggest conditions of life widely different from those of ordinary fishes. Their power of swimming would appear to have been small, for their arms or fins seem, as suggested by Owen, to have been better fitted for shuffling along the muddy or sandy sea-bed, than for rapid movement through the waters,

[1] By Günther these fishes are placed in his sub-class Palæichthyes.

so that in this respect they were ill-suited either to avoid their pursuers or to pursue their own prey. They seem to have been more adapted to burrow in soft mud or silt, where the unprotected part of their body was covered up and hidden, and only their mailed head and trunk remained exposed, free to catch their passing prey, yet safe from attack by their

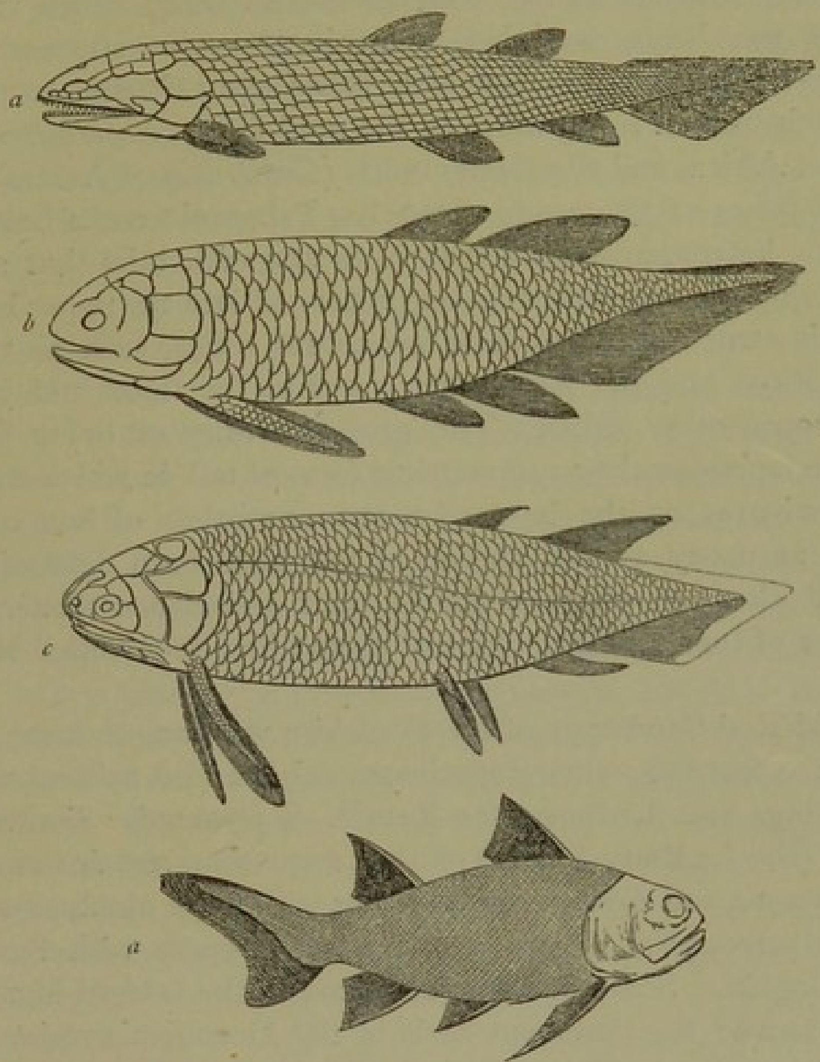

FIG. 39. Lepido-ganoid Fishes of the Devonian Period.
a. Restoration of Osteolepis (after Pander). *b. Restoration of Glyptolepis* (after Huxley). *c. Holoptychius* (after Huxley). *d. Diplacanthus striatus*, Ag.

enemies, in a manner analogous to the habits of some few recent fishes. One such species frequents the delta of the Ganges.

Besides these aberrant forms, there are other fishes approaching more closely to living forms, such as *Osteolepis*, *Glyptolepis*, and *Holoptychius*, some of which are allied to the *Polypterus* of the Nile and other African rivers; but they present peculiarities of structure, which have led Huxley to include them in a new division, the *Crossopterygidæ*, or fringe-finned fishes. The genus *Diplacanthus*, characterised by its very small scales, is altogether confined to Devonian strata.

The latter group of fishes characterises more especially the Upper part of the Old Red Sandstone of Scotland. The *Holoptychius nobilissimus* abounds in the yellow sandstones of Dura Den, near St. Andrews, where they seem to have been suddenly killed and rapidly entombed, so that hundreds of specimens are spread out on the flat surfaces of the rock, with every scale in position, almost as perfect as living fishes.

Numerous remains of the *Plagiostomi*, an order which includes the Sharks and the Rays, are also found in Devonian strata; while it is probable that other of the Devonian fishes are referable to the *Dipnoi*, and have their nearest living allies in the mud-fishes (*Lepidosiren*) of South America and Africa, and the Barramunda (*Ceratodus*) of Australia.

All the fishes of these and the other Palæozoic rocks belong to the division with heterocercal tails, that is to say with tails that are unsymmetrical, having the vertebral column prolonged into the upper lobe (Vol. I. p. 74). This structure exists in a few recent fishes, such as the Sharks, Sturgeons, Rays, and the *Lepidosteus*; and in the fœtal and young individuals of some other fishes. The great majority of living fishes have, however, the homocercal or symmetrical form of tail, in which the vertebral column terminates at the base of a tail consisting of two equal lobes. Altogether, as many as 120 species of fish have been determined in the Devonian Rocks. In consequence of their abundance relatively to the other groups of fossils, this geological period has been called the 'Age of Fishes.'

The Old Red Sandstone of Herefordshire was long thought to be non-fossiliferous; a few fragmentary specimens only had been found, when in the railway-cuttings near Ledbury, the Rev. W. S. Symonds[1] discovered in the lowest beds (the Ledbury Shales) of that formation, remains of *Pterygotus*, *Onchus*, *Pteraspis*, and *Cephalaspis*, together with large numbers of the head-shields of *Auchenaspis*. There were few other fossils with the exception of a large Lingula. Some fine specimens are in the Oxford Musuem.

In **Ireland**[2] the basement beds of the Devonian consist of conglomerates which rest *unconformably* on the Upper- and Lower-Silurian strata, while upwards they pass into sandstones and shales, to which succeeds *conformably* the Yellow Sandstone forming the base of the Carboniferous series. Professor Hull considers that these represent only the Upper Devonian, and that the whole of the Middle and Lower Devonians are wanting, and shows which are the equivalent beds in England, Wales, Scotland, and Belgium. The Irish section is of peculiar interest; for, while the upper beds contain the same species of Brachiopods as the Pilton beds of Devonshire, lower beds contain remains of *Coccosteus*, *Pterichthys*, *Glyptolepis*, and other fishes of the Old Red Sandstone, and associated

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1 'Quart. Journ Geol. Soc.,' vol. xvi. p. 193, and vol. xvii. p. 152.

2 'Quart. Journ. Geol. Soc.,' vol. xxxvi. p. 255; and Kinahan's 'Geology of Ireland.'

with these are the abundant and well-preserved remains of the fine fern (*Palæopteris Hibernica*, Forb.) and the *Anodonta Jukesii*, Forb.

Scotland. Mr. R. A. C. Godwin-Austen inferred from the presence of this Anodonta and its associated fern in Ireland,—the abundance of plant remains in Caithness (where *Estheria* also abounds),—and the peculiar character of the cuirassed fishes of Scotland and Herefordshire, that the Old Red Sandstone was deposited in great freshwater lakes; and Dr. A. Geikie, in an important memoir on the Old Red Sandstone of Scotland [1], has shown that it occupies five great areas or basins, which he considers to represent so many such lakes. It is divided into an Upper and Lower series. The latter consists of red and yellow sandstones, flagstones, and conglomerates, with occasional seams of limestones, and having a maximum thickness of some 20,000 feet. At places there are enormous intercalated masses of volcanic rocks. The large *Pterygotus*, the *Stylonurus*, and the armour-plated Fishes of Banff and Moray, characterise this series, which also contains land-plants—*Calamites*, *Cyclopteris*, *Sigillaria*, and *Psilophyton*. They abound in some of the flagstones of Caithness and Orkney.

The upper series consists of massive red (occasionally passing into yellow and white) sandstones, red clays, and coarse conglomerates. They lie unconformably upon the Lower Old Red, and pass up conformably into the overlying Carboniferous series. Organic remains are scarce except in a few places. *Estheria membranacea*, which is found also in Russia, abounds near Wick. It is to this series that the celebrated fish-beds of Dura Den near St. Andrews, with their swarms of *Holoptychius*, *Pterichthys*, and other Lower-Old-Red forms, also belong. Dr. Geikie mentions a remarkable fact respecting this Upper Old Red. In the Isle of Arran there has been found, in the middle of these rocks, a bed of limestone containing such common Carboniferous species as *Productus giganteus*, *Spirifer lineatus*, *S. semireticulatus*, etc.

DEVONIAN ROCKS OF THE CONTINENT AND AMERICA.

North of France. The Devonian strata, which dip beneath Triassic rocks in the neighbourhood of Torquay and of Barnstable, and pass under the Oolitic and Cretaceous Strata of the South of England, re-appear, on the other side of the Channel, in the Boulonnais. In that district, however, the Upper division of the Devonian series is alone developed. It consists of a series of quartzites, dolomites, limestones, and fissile sandstones, together about 2,000 feet thick. The limestones are extremely fossiliferous, and abound in fine specimens of various corals.

Owing to the economic value of the limestone, as a marble and

[1] 'Trans. Roy. Soc. Edinb.,' vol. xxvii. p. 347.

otherwise, they are largely worked; and the many quarries, together with the railway-cuttings on the line, which, between Calais and Boulogne, passes through Devonian strata for a distance of two to three miles, expose a number of very interesting sections. These palæozoic rocks then pass under the Chalk hills of Artois, and do not re-appear in mass until the frontiers of Belgium are crossed[1].

Belgium. The Belgian geologists have divided the Devonian into the following groups. The fuller details of this complicated series will be found in the works of Dumont, Dewalque, Dupont, Gosselet, Mourlon, and others.

Upper Devonian (*Systèmes Condrusien et Famennien*).	1. Psammites of Condroz, with *Rhynchonella pleurodon*, *Cucullæa Hardingii*, etc.	Lower Part of the 'Terrain Anthracifère' of Dumont.
	2. Schists of Famenne, with *Cyrtina Murchisoniana*, *Cardium palmatum*, etc.	
	3. Limestone of Frasne, with *Rhynchonella cuboides*, *Spirifer disjunctus*, etc.	
Middle Devonian (*Système Eifelien*).	1. Limestone of Givet, with *Stringocephalus Burtini*, *Spirifer mediotextus*, etc.	
	2. Schists of Couvin, with *Calceola sandalina*.	
	3. Conglomerate of Burnot.	
Lower Devonian (*Systèmes Coblentzien et Gedinnien*).	1. Slates of Houffalize, with *Spirifer macropterus*, *Leptæna Murchisoni*, etc.	'Terrain Rhénan' of Dumont.
	2. Purple and Green Schists of Oignies and Mondrepuits with *crinoid* stems and *orthoceras*.	

These Devonian strata extend the length of the chain of the Ardennes, and thence range into the Rhenish Provinces. They there consist of great beds of conglomerate, formed of pebbles of quartzite derived from the underlying Silurian rocks, succeeded by alternating series of slates, compact sandstones, psammites, limestones, and dolomites. The whole, with the exception of the limestones and dolomites, are generally of a dark-red and purple colour, mottled with green and grey, with a thickness of about 7,000 to 8,000 feet; but it is difficult to form a correct estimate, in consequence of the extremely disturbed and contorted condition of the strata.

Among the species of this period common to England and Belgium are *Atrypa reticularis* (Pl. III, fig. 6), *Orthis tenuistriata*, *Spirifer simplex*, *S. disjunctus*, *S. ostiolatus*, and *S. speciosus*, *Strophomena depressa*, *Avicula Damnoniensis*, *Megalodon carinatus* and *M. cucullatus*, *Murchisonia angulata*, *Phacops latifrons* (Pl. II, fig. 8), and others. The *Rhynchonella pleurodon* is very characteristic of the Upper Devonian.

The break shown by Omalius D'Halloy and Dumont to exist between the Terrain Rhénan and Terrain Anthracifère is rather of a physical than palæontological character; on the other hand, the Belgian geologists generally consider that there is a passage upwards from the Famennian to the Carboniferous system of Belgium.

[1] Except that small areas of Devonian strata form the floor of some valleys amongst the chalk hills. It is with a feeling of surprise that the geologist comes upon these old rocks in a district like that of our Salisbury Plain or the Downs of Wiltshire.

In **Western France** Devonian rocks are not so well developed as their equivalents in England and Belgium. The Lower Devonian with few fossils occupies part of the Normandy promontory, and forms also much of the hilly country of north-western Brittany, so similar in many respects to parts of South Devon.

In the Pyrenees there are extensive beds of brecciated marbles of this age, but the fossils are few and not well preserved. Devonian strata are also met with in the Corbières, the Vosges, and the Morvan.

Germany. The Devonian strata are here again more fully developed. The bold and rugged hills and the vine-clad slopes of the banks of the Rhine and the Moselle are, in great part, formed of rocks of Devonian age, consisting of schistose strata, with intercalated sandstones and quartzose rocks, and with only a few bands of limestone, which are succeeded by strata, in which limestones are more prevalent. Murchison and De Verneuil considered that in this district there was the same triple division that had been established for England. Here, again, while the Silurian rocks are unconformably surmounted by Devonian strata, the latter, as in Belgium, pass upwards conformably into the Carboniferous series.

The Middle Devonian is very rich in organic remains. Amongst the most celebrated localities is the district of the Eifel, so well known also for its extinct volcanoes. The limestones of that district are laden with a profusion of well-preserved shells, corals, crinoids, and other fossils, many of which are of the same species as are found in England, such as *Stringocephalus Burtini* (Pl. IV, fig. 1), *Phacops latifrons*, *Calceola sandalina*, *Goniatites*.

In other parts of Germany minute bivalved Crustacea (*Entomis*, formerly called Cypridina) and a cephalopod (*Clymenia*) so abound in some beds of the upper division that they are respectively called *Cypridinen-Schiefer* and *Clymenien-Kalk*.

Thus far eastward the Devonian series has retained essentially the fossils of the Devonshire type, although in the Eifel a few specimens of *Coccosteus* and other fishes[1], which constitute so marked a group of the Old Red Sandstone of Scotland, have been found.

Russia. Proceeding further eastward, however, the Devonian rocks in Russia, instead of presenting the type of either Devonshire or of Scotland alone, contain the fossils of both groups, and thus afforded Murchison important evidence in correlating the limestones and slates of Devonshire with the red sandstones and conglomerates of Herefordshire and Scotland.

In Russia, red sandstones alternate with bands of limestone, and, while the sandstones contain the remarkable fishes found in the north of Scotland,—the *Coccosteus, Osteolepis, Diplopterus*, and *Dipterus*, together with such identical species as *Holoptychius nobilissimus*, *Dendrodus strigatus*,

[1] Some few scales and fragments of similar fishes, however, have been met with in the schistose rocks of Devon.

D. biporcatus, *D. incurvus* and *Pterichthys major*,—the limestones contain shells identical with species of the Eifel and Devonshire.

America. The Devonian strata of North America occupy large tracts flanking the Appalachian Chain. They consist of a series of grits, limestones, sandstones, and flags, of various colours, which vary in thickness from 500 feet on their western boundary to 15,000 feet in their more easterly area. They have been divided by the American geologists into a series of divisions or periods; and these again have been subdivided into epochs or groups, referable to an Upper and a Lower Devonian series.

Period.	*Epoch.*	
1. Catskill ...	Catskill Group	Upper Devonian.
2. Chemung ...	Chemung ,, ...	
	Portage ,, ...	
3. Hamilton ...	Genesee ,, ...	
	Hamilton ,, ...	
	Marcellus ,, ...	
4. Corniferous ...	Upper Helderberg Group	Lower Devonian.
	Schoharie ,,	
	Cauda-galli ,,	

The terms of the American divisions are generally derived from local names; but the 'Corniferous' is derived from the circumstance of the layers of flint which are interstratified with the layers of limestone, being of the variety called Hornstone. Like the flint of the English Chalk, the hornstone of the Corniferous limestone abounds in beautiful microscopic fossils, amongst which are Desmids (?), Sponge spicula, Diatoms, &c. The Cauda-gallic epoch has a more fanciful derivation. The term alludes to the feathery forms of a common fossil, supposed to be a sea-weed (Dana).

It is in the limestones of this period that the great deposits of mineral oil occur. This oil has risen in places through fissures to the surface, and covered it with inspissated bitumen. But where the limestone passes under newer rocks, the oil can only be reached by artesian borings, some of which are nearly 2,000 feet deep; and the oil, which at those depths is in a state of perfect fluidity, rises, like water under similar circumstances, to the surface in large quantities. Mineral oil is also obtained from the Genesee group; in this case it is not given off in a free state, but is obtained by distillation from shales.

There is little doubt but that this oil has been formed by the natural distillation or decomposition of organic matter under heat and pressure; but, whereas in the Carboniferous series the presence of bituminous matter is generally due to the decomposition of vegetable matter, its presence in these Devonian rocks is, in all probability, due to the decomposition of animal matter, derived from the Fishes, Crustacea, Mollusca, and other forms of life, the remains of which abound in so many of the limestones. The shells and the cells of corals are sometimes filled with bitumen, like the shells in the Tertiary fresh-water marls near Clermont in Auvergne, and sometimes those of the Carboniferous Limestone of Derbyshire.

Again, as in the coal-measures, there is often an evolution of inflammable gases, the result of decomposition, which in some of the oil regions is given off in such quantities from the bore-holes, as to be available for house-warming and lighting, and other economical purposes.

Corals abound, including species of *Cyathophyllum*, *Favosites*, *Syringopora*, and *Aulopora*; together with Crinoids of the genera *Nucleocrinus*, etc.

Amongst the *Crustacea*, the Trilobites, as in Europe, nearly come to their end with the Devonian strata. Species of *Phacops* are, however, common with others belonging to the genera *Dalmania* and *Proëtus*.

The Molluscan fauna of these Devonian rocks is of the same general character as that of Europe. Amongst *Brachiopods*, Spirifers are very common, and the same broad-winged forms predominate. *Productus* makes its first appearance; and, amongst the *Cephalopoda*, Goniatites. The former commences in the Corniferous period, and becomes extinct in the Carboniferous. The latter has a shorter range than in Europe, commencing in the Hamilton and becoming extinct with the Carboniferous period.

Cuirassed Fishes of the same genera as in England, such as the *Cephalaspidæ*, etc., are found also in the Corniferous strata of America. Others were formidable creatures. One genus, the *Onychodus* of Newberry, had 'jaws from a foot to a foot-and-a-half long, with teeth two or more inches long in the lower jaw, and three-fourths of an inch in the upper. Some of these fishes probably had a length of twelve to fifteen feet' (Dana). The remains of the shark tribe are also common, including the *Hybodonts*, which had sharp cutting teeth like most modern sharks, and *Cestracionts*, like the modern *Cestracion* of Australia, with crushing teeth.

The American Devonians also furnish the first evidence of the existence of Insects. One gigantic species (the *Platephemera antiqua* of Scuder) measured five inches in spread of wings, and is related to the *Ephemeræ*, or Mayflies—species whose larvæ live in the water, or frequent moist places.

Another point of much interest connected with the American Devonians is the large increase in terrestrial vegetation, which greatly exceeds that of Europe. Whereas in the Lower and Middle Silurians, there are only the uncertain Eopteris, and the disputed *Protostigma*, and the few other remains recorded by Lesquereux ('Geol. Mag.,' 1878); and in the Upper Silurian only two or three *Lycopodiaceous* plants,—in the Devonian period there are numerous land plants, namely, Lycopods, Ferns, and Gymnospermous exogens, the whole constituting an abundant Flora. Sir J. W. Dawson[1] has also described a large number of new forms from the rich localities of St. John in New Brunswick and Gaspé in Canada. The *Lyco-*

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[1] 'Quart. Journ. Geol. Soc.,' vol. xviii. p. 296, vol. xix. p. 458; see also Hall's 'Reports on the Geology of New York;' and Prof. W. B. Roger's 'Report on Pennsylvania.'

podiaceæ are represented by *Lepidodendron* and other genera abounding in the succeeding Carboniferous period. *Cordaites* and *Psilophyton*, though not confined to the Devonian strata, are very characteristic.

The curious Lycopodiaceous plant, *Psilophyton*, of which there are three species, is common at Gaspé. Sir J. W. Dawson states that it there fills many beds with its rhizomes in the manner of the Stigmaria of the Coal-measures. Another uncommon form is the *Cordaites*, now referred to the Coniferæ, the leaves of which are abundant at St. John's, where they are associated with beds containing other plants and *Lingulæ*. In some places plants so abound that they have formed thin seams of impure coal. Amongst Ferns are *Cyclopteris*, *Neuropteris*, *Pecopteris*, the trunks of large tree-ferns referable to the genera *Protopteris*, *Caulopteris*, etc., with *Sigillaria* and *Stigmaria*, *Calamites*, and *Asterophyllites*, all common Carboniferous genera.

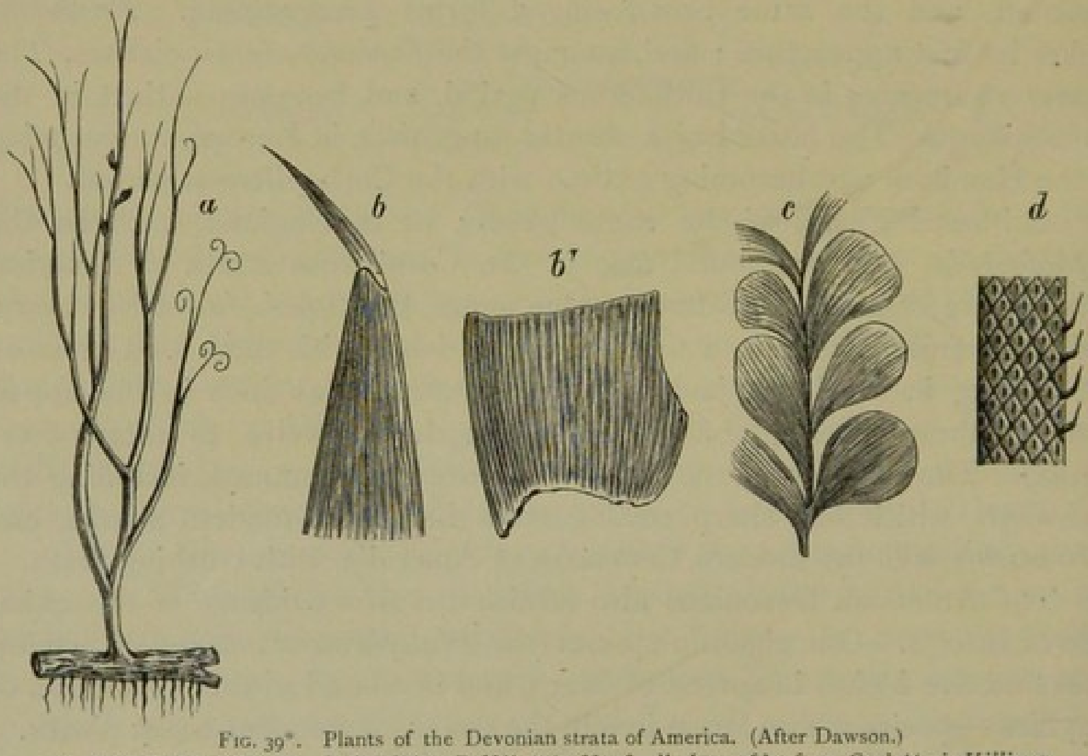


FIG. 39*. Plants of the Devonian strata of America. (After Dawson.)
a. Psilophyton princeps. b. Cordaites Robbii, top of leaf. b'. base of leaf. c. Cyclopteris Hilliana. d. Lepidodendron Gaspianum.

The ordinary *Conifers* belong to the genus *Prototaxites*; specimens of the trunk of this tree have been found three feet in diameter, showing that even then there were forests of ancient yew trees. Amongst others were *Dadoxylon* and *Ormoxylon*. Small fruits or seeds, known by the name of *Cardiocarpon*, *Trigonocarpon*, abundant in the Coal-measures, also occur in the Devonian rocks. They probably belonged to trees of the Salisburia type.

In all, the American geologists enumerate about 120 species of land plants belonging to this period, and consider that they show a greater variety and diversity than prevailed in the more uniform vegetation of the succeeding Coal-measure vegetation.

CHAPTER VII.

THE CARBONIFEROUS SERIES.

Range and Divisions. The Carboniferous Limestone and Shales. The Millstone-grit. The Coal-measures. Variation in Thickness. Thickness of Coal and Rock in the several Coal-fields. Area of, in Britain. Varieties of Coal-Shales. Iron and other Minerals. Clays and Building-Stones. Faults: Effects of Lateral Pressure; Magnitude of; Forming watertight compartments; No difference of level visible on Surface; Other Disturbances of the Strata; Angle of Dip. Symon and Horse Faults. Depth of Working. Organic Remains: Protozoa; Corals; Echinodermata; Crustacea; Mollusca; Fishes; Reptiles. Plants: Ferns; Lepidodendron; Sigillaria; Calamites; Conifers; Cycads. Formation of Coal. Forest-growth. Tree-stumps. Sporangia. Woody Structure. Variety in Coals.

Overlying the Old Red Sandstone and Devonian strata is a series of rocks of the highest importance, both in their palæontological and economical aspects. Their importance geologically consists in the enormous development of terrestrial plants, and economically in the vast supplies of fossil fuel, limestone, and ironstone stored up in them for the use of man.

Range and Divisions. Largely developed in Great Britain, Carboniferous strata likewise range over considerable portions of the Continent of Europe, many parts of Asia and Australasia, and are spread over vast tracts of the American continent. From the circumstance that their products are so useful to man and in consequence so extensively worked, the physical structure and organic remains of these rocks are known in more detail and under a greater variety of conditions than those of any other Formation in the geological series. The Carboniferous system derives its name from the frequent presence of productive seams of coal; for, although beds of coal are met with in various other Formations, both of Secondary and Tertiary age, they are not often profitably worked, being generally either deficient in quantity or indifferent in quality, although there are some notable exceptions. The lower portion of the Carboniferous series takes its name from the bold and elevated character of the scenery which it sometimes forms in this country, whence the use of the term 'Mountain-limestone,' originally applied to the Carboniferous

Limestones of the hills of Derbyshire and the Pennine chain of Northern England. The Carboniferous series is divided, as under, in descending order :—

1. Upper Coal-measures, and the Lower or Gannister Series.
2. Millstone-grit.
3. Upper Limestone-shales (Yoredale Series).
4. Carboniferous, Scar, or Mountain-limestone.
5. Lower Limestone-shales (Tuedian of the North, and Calciferous Sandstone of Scotland).

The thickness of these several divisions varies very greatly; on an average we may estimate their aggregate thickness in this country to amount to as much as from 8000 to 12,000 feet.

The Limestone and Shales. In the South of England the lowest division is wanting, and the limestone presents a solid mass, intercalated with but few beds of shale. The lime-rocks are of various colours, generally grey, but sometimes mottled red, yellow, and black, and are occasionally oolitic. They are about 2000 feet thick. As this division trends northwards into Derbyshire and Yorkshire, the limestone becomes gradually intercalated above and below with beds of shale and sandstone, and thus attains a thickness of from 4000 to 6000 feet. The upper group is termed the Yoredale series; and the lower, the Scar Limestone. The limestone beds go on diminishing in importance, and in the extreme north of England and in Scotland they become altogether subordinate to the other strata, forming a lower sub-division, known as the Tuedian and 'Calciferous Sandstone series.' In Northumberland and Scotland this series contains productive beds of coal and ironstone, and in the lower part it is intercalated with conglomerates and sandstones, having very much the aspect of the Old Red Sandstone. Thus, while in the south of England the Carboniferous or Mountain Limestone and the Coal-measures form well-marked and perfectly independent divisions, they become—by the thinning out of some beds and the setting in of others, by the increase of coal-seams in one part, and of shales, sandstones, and limestones in another, as they range north—so intermingled, that these divisions lose their individuality, and assume the general character of a consecutive series.

The Carboniferous Limestone gives its impress to the physiography of many parts of England. Massive beds of it, rising at a high angle from beneath the Mesozoic strata in the neighbourhood of Frome (Vol. I, p. 251) and Wells, constitute the main range of the Mendips. The well-known 'Cheddar Cliffs' are formed by a transverse rent through these rocks. Spurs from this range run westward to the coast at Weston-super-Mare and Brean Down. The outcrop of the Limestone then ranges northward to Clifton, where it is traversed by the gorge of the Avon; here it is also opened out by several large quarries.

A few miles further north, the Limestone passes under the great Triassic plain of Central England to re-appear in the picturesque hills of Derbyshire, the bluffs of Matlock, the scarps of Dovedale, and the high ridges of Buxton. It is there that it presents the conspicuous extensive intercalated beds of contemporaneous lava-flows, locally known as 'Toadstones' (Vol. I, p. 377).

In Yorkshire the Limestone hills, which rise to heights of 2000 to 2500 feet in the fine range of the Pennine chain, are intersected by the many beautiful 'dales' so characteristic of that district. The Carboniferous series then passes through Northumberland, where the Limestone is traversed, as it is in Flintshire, by numerous lead-veins; thence into Scotland, where it it marked by the number and magnitude of the associated igneous rocks, and its greatly altered petrological characters.

The prevailing clear cold grey colour of the Limestone throughout its range, the frequency of bared surfaces, and the innumerable caves (many of them the dens of Pleistocene Mammalia—others famous for their magnitude and their stalactites), render these rocks easily recognisable, and contribute greatly to scenic effect in the districts they form.

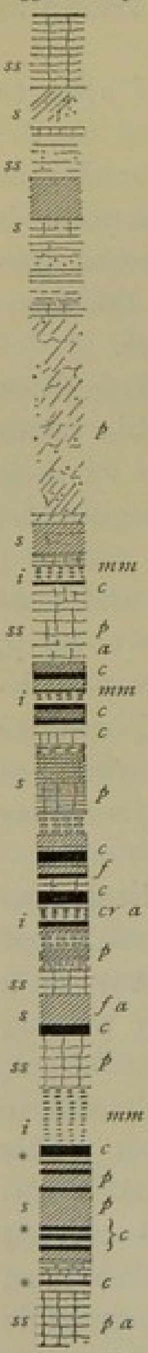
Whereas in England the Carboniferous series forms bold and conspicuous hills, in Ireland it forms the great central plain of the country, though it rises into hills in the north-western counties, and attains a thickness of 2000 to 3000 feet. The limestone, as in parts of England, contains thin beds and amorphous masses of flint or dark chert, sometimes of large dimensions. The black limestone of Kilkenny and the red limestone of Cork form handsome marbles.

The Millstone-grit in the Mendip Hills and near Bristol consists of very compact sandstones and grits, yellow, grey, or red, from 500 to 1000 feet thick. In Central England it is more generally of a lighter colour, and is often full of pebbles of white quartz, passing into a conglomerate; and at other times it abounds in grains of felspar, and passes into an arkose. It also contains occasionally subordinate seams of coal; and, when micaceous, forms excellent flagstones. This formation attains its maximum thickness in South Lancashire and Yorkshire. In these districts and in Derbyshire it forms high heath-covered hills, nearly bare of soil and without wood, well suited, from the hard texture of the rocks, their insolubility, and the absence of permeable strata, to serve as catchment areas for the rain-water; for this purpose they are used to furnish the water-supply of several of the large towns of those districts.

In Northumberland, the Millstone-grit consists of coarse grits and shales, and diminishes to a thickness of 400 feet; while in Scotland it is represented by light-grey and reddish sandstone (the Moor Rock) with thin seams of coal and some bands of ironstone.

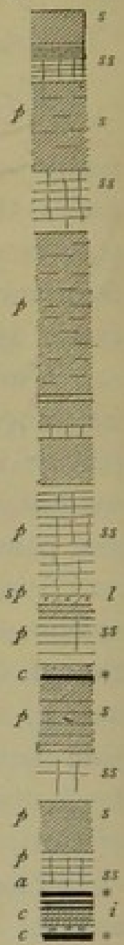
The Coal-measures consist of alternating strata of light-coloured sandstones, dark-grey clays and shales with ironstones, and a certain number of seams of coal (Fig. 40). These latter, as also all the associated strata, are extremely variable, both in thickness and in range. While the variation of the coal-seams, however, is to be counted by inches or feet, that of the shales and sandstones is to be reckoned by yards and fathoms. Owing to these variations in the dimensions of the component strata and the thinning-out of some of the beds, it is often extremely difficult, if not impossible, to identify or correlate the seams of coal in adjacent Coal-fields, or even in different outlying districts of the same Coal-field.

FIG. 40 A. Pit near Woombridge, 538 ft. deep.



c. Coal-beds.
p. Plants.
mm. Marine mollusca.
a. Anthrocosia.
f. Fishes.
cr. Crustacea.
s. Shales.
ss. Sandstones.
i. Ironstones.

FIG. 40 B. Pit near Broseley, 397 ft. deep.



sp. l. Spirorbis limestone.
** The same seams in the two sections.

Some remarkable instances of these variations have been noted in the Staffordshire Coal-field. In one place, near Wolverhampton, nine coal-seams are separated by beds of sandstone, having an aggregate thickness of 420 feet, all of which thin out in a distance of five miles, as they range from South to North, thus bringing the separate Coal-seams into near juxtaposition.

Another well-known instance is that of the Ten-yard coal of the Dudley district. This does not consist of one seam, but is the result of the junction of thirteen seams, which in one part of the field are worked as distinct beds, separated by many feet of shale and sandstone; but in the Dudley district, owing to the thinning-out of the intervening strata, they are brought near together and worked as one bed.

These instances might be indefinitely multiplied, for the variations are the rule and not the exception. The total thickness of the Coal-measures and the number of the Coal-seams are consequently subject to great variation.

The great Coal-field of Northumberland and Durham is about 3000 feet thick, and the number of workable seams sixteen, having a total thickness of forty-six feet. In Derbyshire and Yorkshire the Coal-measures increase to a thickness of 4500 feet, with thirty-five seams of Coal, forming an aggregate mass of ninety-nine feet.

In the Leicestershire and Warwickshire district, the Coal-measures diminish to 2500 or 3000 feet with from eight to twelve seams of workable Coal, together from thirty to forty-five feet thick.

In the important district of South Lancashire and Manchester the Coal-measures are 6000 feet thick, with a total thickness of Coal not much less than 100 feet.

In North Staffordshire, the total thickness of the Coal-measures is 5000 feet, with about thirty workable coal-seams, having an aggregate thickness of 130 feet; and in Shropshire

(Coalbrookdale) 1200 feet, with seventeen seams of Coal, having a total thickness of fifty feet in the northern part of the Coal-field, decreasing in a distance of nine miles as they range south to five seams with a thickness of fourteen feet. These changes of composition and dimensions are shown in the pit-sections Figs. 40, A. and B, which are seven miles apart.

In the Bristol and Kingswood Coal-field the Coal-measures attain a thickness of 7000 to 8000 feet, in the centre of the field; and at Radstock, near Bath, the number of Coal-seams amounts to as many as forty-six, with a total thickness of ninety-eight feet of Coal. They become rapidly reduced, however, as they trend north, so that at a distance of twenty miles from Radstock only seven seams, having a total thickness of sixteen feet, remain.

In the great Coal-field of South Wales the Coal-measures attain their maximum dimensions of from 10,000 to 12,000 feet, with 75 seams of Coal, which together have a thickness of 126 feet.

The superficial area of the known English Coal-fields amounts to about 6000 square miles; besides these, Professor Ramsay estimates that there may be about 2200 square miles of unexplored Coal-measures beneath the Permian and New Red Sandstone of the Midland and Northern Counties. To this may possibly hereafter be added certain Coal-basins that there is reason to suppose exist beneath the Tertiary and Cretaceous strata of the South of England, but of these no estimate can at present be formed [1].

Coal differs very materially in its quality, and in the proportion of foreign ingredients with which it is mixed. Not only do the several Coal-fields yield different qualities of Coal, but also the various seams in the same field yield different varieties.

Coal may be divided into four principal sorts. 1. *Bituminous or Caking Coal*; 2. *Splint or Dry Coal*; 3. *Cannel or Parrot Coal*; 4. *Anthracite or Stone Coal.*

1. **Caking or Bituminous Coal** burns with a bright flame, gives off spurts of gas, leaves many cinders, and little or no ash. It tends also to run together as it softens in the fire, and also to form clinkers. It breaks commonly, when fresh, into small fragments, with a short uneven fracture. The Wallsend Coal is a well-known example of a caking Coal.

2. **The Splint or Dry Coals** may be divided into two sorts:—(1) the hard Coals which have a long even fracture or cleavage, and are got in large blocks; and (2) the soft or Cherry Coals which have a short fracture. These Coals have a bright resinous lustre, occasionally masked by thin films of gypsum. They burn with a bright cheerful flame, do not cake, require little stirring, keep long alight, and leave more or less white or brown ash. Amongst these are the Moira and the Silkstone coals.

3. **Cannel Coal** is so called from its burning with a clear flame like a candle. It is generally compact,—has a waxy and dull lustre, and does not soil the fingers. It burns away like wood, leaving only a white ash; and may often be turned in a lathe and worked like wood—in that respect somewhat resembling jet.

4. **Anthracite or Stone-coal** is heavier than common Coal, has a more massive fracture, and a semi-metallic lustre; does not soil

[1] The reader will find in Professor Hull's 'The Coal-fields of Great Britain' full details of the structure, extent, and resources of all our Coal-fields. The Report of the Royal Coal-Commission of 1866 gives other details of our Coal-fields from an economical and statistical point of view.

the fingers, is difficult to light, and does not flame. It burns with great heat, and without smoke; much of the Welsh Coal is Anthracite.

These constitute the chief distinctive varieties of Coal; but the number of minor varieties known in the London market amounts to about seventy. Caking Coals predominate in the Newcastle and Durham Coal-fields; and Dry Coals, including the Splint and Cherry Coals, in the Scotch, Midland-Counties, and Somerset Coal-fields.

When Coal is pure, it does not contain above two or three per cent. of inorganic matter; but this sometimes increases to such an extent that the Coal yields, on burning, thirty per cent. of ash, or even more. It is also sometimes so mixed with shale and sandstone as to be useless. The specific gravity of coals varies from 1·25 to 1·46.

Besides the different varieties of Coal, the shales associated with the Coal-measures often contain so much carbonaceous matter as to be combustible, or to yield by distillation the many useful products which have given such value to some of the Scotch Coal-measures. The Torbane mineral or Boghead Coal, of which the primary products are naphtha and paraffin, is one of the most important of these substances.

The carbonaceous matter has sometimes taken a liquid form, and is then found in the crevices of the rocks in the condition of *Bitumen*, or mineral tar. It is occasionally present in such quantities as to ooze out of the rocks, as in the case of the tar-spring which some years ago issued from one of the Coal-measure sandstones of Coalbrookdale, but has now ceased to flow.

Iron combined with sulphur, as iron-pyrites, sometimes in the form of small nodules and tabular masses, at others diffused in thin films which give a beautiful iridescent appearance to the coal, is constantly present in coal. It is the presence of this mineral that so often causes spontaneous combustion; for, when water or moisture gains access to it, the affinity of both the iron and sulphur for oxygen leads to the conversion of the sulphide of iron into the sulphate, and so much heat is generated as frequently to lead to the spontaneous combustion of the coal.

Iron, however, is more generally present in the shales of the Coal-measures as a carbonate of the protoxide of iron (*Chalybite*), combined with more or less clay and a small quantity of carbonate of lime, in nodules or concretions dispersed through them in layers, like flints in the Chalk. The proportion of iron varies from thirty to thirty-six per cent. This form of iron-ore is largely worked in most of our coal-fields. When it alternates with coal in very thin seams, it constitutes the 'black bands' which are worked very profitably, as it needs only the addition of limestone for a flux.

When instead of the clay-iron-ores the shales contain iron-pyrites the same decomposition takes place, on exposure to air and moisture, as occurs in coals when so exposed. But in this case, part of the sulphuric acid produced by the decomposition of the iron-pyrites combines with the alumina which constitutes the base of the clay, and forms the sulphate of alumina. If potash or soda be present in the shale, or be added to it artificially, double salts of sulphate of alumina and potash or soda, known as alum, are formed. This process is largely carried on in the Lanarkshire coal-field.

Among the smaller and less important mineral substances associated with the Coal measure ironstones are blende or sulphide of zinc, and some unascertained form of titanium.

Fire-clays, etc. Where the shales or clays of the Coal-measures are free from foreign ingredients, and especially from lime or alkaline earths, they afford a material which is capable of resisting great heat without vitrifying. The celebrated Stourbridge fire-clay[1] of the Dudley coal-field is a well-known instance of clays of this class. The coal-seams have commonly a substratum of clay.

The importance of some of the Coal-measure sandstones as building-stones is considerable. The cities of Edinburgh, Glasgow, and the new part of Newcastle are chiefly built of such stones, which are very durable; for, as they rarely contain carbonate of lime, they are not acted upon by chemical-atmospheric influences. The most remarkable mass of sandstone strata connected with the Coal-measures proper is 'the Pennant,' which is found in the Bristol and South-Wales coal-fields, and has in the former field a thickness of 2000 feet, and in the latter 3000 feet. It lies in the middle of the Coal-measures, and divides them into an upper and a lower series. From the Yorkshire coal-fields are obtained most of the thin-bedded micaceous sandstones used extensively for foot-pavements in London and elsewhere.

Faults of the Coal-measures. These require special notice, not because faults are more common in the Coal-measures than in many other Palæozoic formations, but because in these they have been traced and measured in much greater detail than in any other strata; and on account of their interference with the workings.

These faults extend, according to their magnitude, for a few hundred yards, or for many miles. They are accompanied by an elevation of the strata on one side, and by depression on the other, which are called by the miners the *upthrow* and the *downthrow*. The change of level in the strata, produced by these dislocations, varies from a few inches to several hundred yards. The direction they follow is more or less in a straight line, although when long they may vary from it considerably. The dislocation also is rarely vertical; it is generally more or less inclined, and the raised

[1] For the analysis of this and other clays, see vol. i. p. 27.

strata are almost always on the underside of the slope of the fault, towards which their fractured edges commonly dip, while on the other or upper side (the *hade*) they rise towards the fault, and as it is termed 'the downthrow goes with the hade.' Where the contrary happens, it is termed a reversed fault, but these are of rare occurrence. (See Vol. I. chap. xv.)

If therefore the miner, on coming to the plane or face of a fault, finds that the strata suddenly rise, he judges that he is on the lower side of the

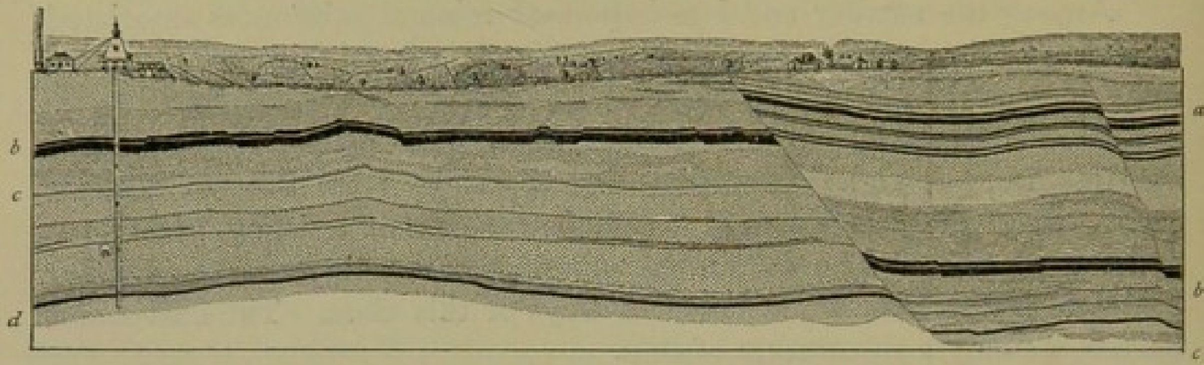


FIG. 41. *Section in the Coal-field of Blanzy.* (After Burat.)

fault, and that he will there have to look for the seam of coal on the other side at a higher level than where he is working. If, on the contrary, he finds the strata suddenly dip, he infers that he is on the higher segment of the measures, and accordingly, after passing the fault, searches downwards.

The edges of the dislocated strata on each side of the fault are sometimes in nearly close contact; but at other times they are separated by several feet of broken strata, rubble, pounded rock, and clay; the latter

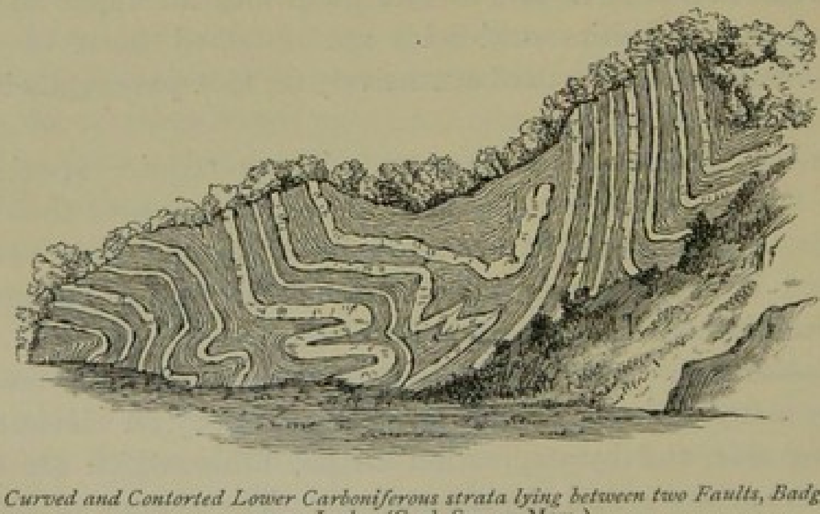


FIG. 42. *Curved and Contorted Lower Carboniferous strata lying between two Faults, Badger's Clough near Leek.* (Geol. Survey Mem.)

condition being due to some irregularity in the walls of the fault, and not to the gaping caused by rupture asunder. That, on the contrary, the dislocation has been generally attended with powerful lateral pressure (Fig. 42), and friction, is shown not only by the frequently curved ends of the strata, but also by the grooved and polished state of the broken edges, which sometimes exhibit faces as smooth and bright as polished marble.

These surfaces are known to the miners under the name of 'Slickensides.' They are of common occurrence in disturbed districts, not only in Coal-measures but likewise in other strata, and are often accompanied by striation closely resembling that produced by glacial action[1] (see Fig. 121, Vol. I).

Sometimes faults follow in rapid succession, a few feet or a few yards only apart, but then usually they are not large. The greater faults are generally at long distances apart. Amongst the largest and best known is one in the Durham coal-field, called the ninety-fathom dyke, which is accompanied by a great difference of level in the strata at one point, amounting to as much as 1200 feet. In the Lancashire coal-field there are two parallel faults near Wigan, producing dislocations, respectively, of 600 and 1800 feet; and near Manchester there is a fault which is supposed to have a downthrow of upwards of 3000 feet (Fig. 43). Far more frequently the faults of the Coal-measures range within the limits of from 10 to 100 feet.

Although these disturbances greatly interfere with the work of the miner, they, at the same time, greatly add to his safety by isolating the many detached segments of the Coal-measures, and forming of them, as it

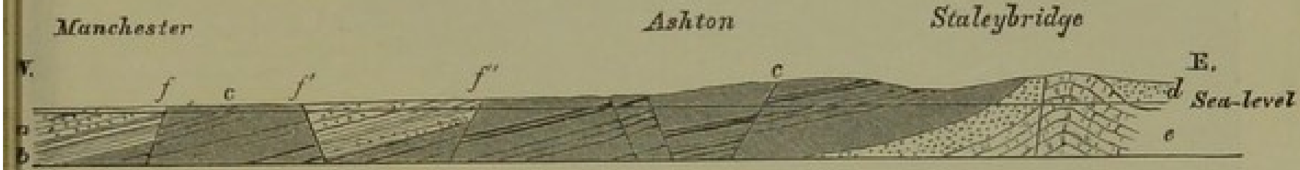


FIG. 43. Section across the Manchester Coal-field from West to East. (After the Geol. Survey.)
(Horizontal and vertical scale ¼ inch = 4000 feet.)
a. Trias. b. Permian. c. Coal-measures. d. Millstone-grit. e. Yoredale Rocks. f, f', f''. Faults.

were, so many water-tight compartments, in which, when once drained, the miner can generally work with safety; if he taps adjacent compartments he may be flooded with water.

It is a remarkable fact that, notwithstanding the excessive irregularities which the variable levels of these separate sections must at one time have produced on the surface, generally not a trace of these differences is now exhibited on the ground above. For example, from Newcastle to Sunderland the ground is almost a dead level; and from Manchester to Liverpool there are no hills rising more than 200 feet above the surface. Yet under those surfaces, the strata are fractured and disjointed to the extent of many hundred, and sometimes many thousand feet. But all now is planed down to one uniform level, and the eye of the most practised geologist cannot, as

[1] It differs, as a rule, in the greater uniformity of the parallel lines and a few other minor points.

a rule, detect any want of regularity, or any indication of the fractured state of the strata below (Fig. 43), except perhaps by changes of colour in the soil.

Not only are the Coal-measures affected by fractures, but the strata are also tilted at various angles; so that, while sometimes the miner follows an easy incline of a few inches in the yard, at other times he has to work at seams which slope like the roof of a house. In other places, again, the coal-beds are thrown up into a vertical position. There are coal-pits on the flanks of the Mendip Hills commenced at the outcrop of the coal-seam, and actually sunk 400 feet perpendicular in the same bed of coal.

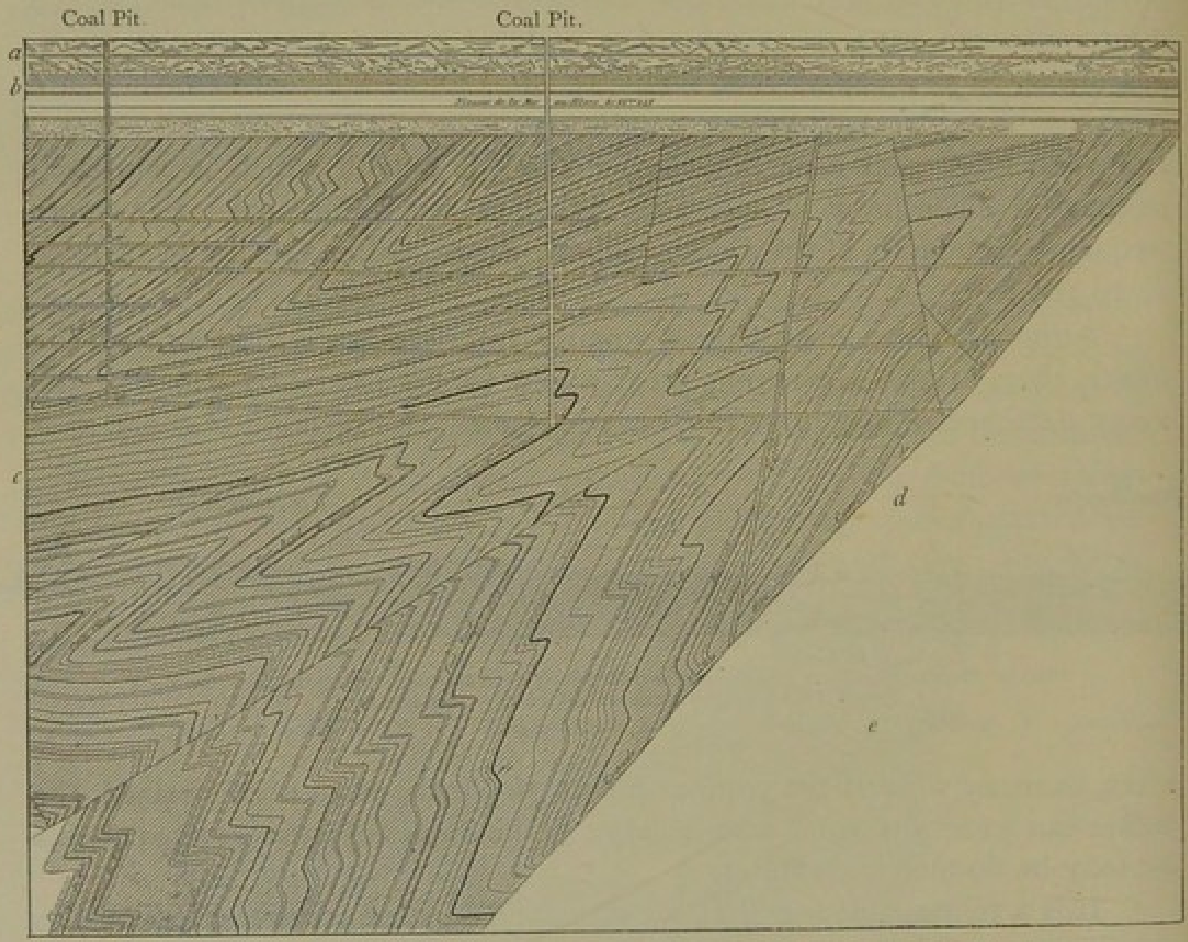


FIG. 44. Diagram Section in the Collieries of St. Vaast Anzin; Coalfield 'Du Nord.' (After Burat.)
a. *Lower Tertiary Strata*, and b. *Chalk* (300 to 400 feet). c. *Coal-measures*. d. *Great Fault*. e. *Broken Ground*.

In other places, the Coal-measures have suffered the most violent contortions, and are twisted backwards and forwards at very sharp angles, so that in sinking a shaft the same coal-bed will sometimes be traversed two or three times. This is particularly the case in Belgium and the North of France; and similar instances, but on a smaller scale, occur in some of the coal-mines on the flanks of the Mendip Hills (see Pl. p. 260, Vol. I).

Symon and Horse Faults. Local irregularities in the coal-beds, known under these names, require some notice. They are not faults in the true sense of the word, but are interruptions, due to other causes, in the continuity of the coals for a greater or less distance. The coal in these cases has been eroded and removed along broad channels, on each side of which it is broken and deteriorated. Such a case is described by Mr. Buddle in the Forest of Dean[1]. The channel there is from 170 to 340 yards wide, and has been traced for a distance of more than 1½ mile.

Another remarkable instance of a Symon-fault is that in the Coalbrookdale coal-field, described by Mr. Marcus Scott[2]. It has removed five seams of coal, and extends for a distance of above two miles with a width of about one mile, having formed a submarine valley of denudation about 150 to 200 feet deep, filled up with upper unproductive Coal-measures.

The first is a case of rather frequent occurrence, and is due probably to erosion of the original peaty mass before complete submergence, and the subsequent filling up the irregularities in the eroded surface of the coal

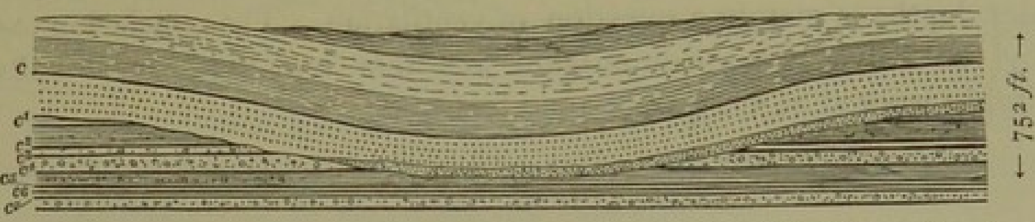


FIG. 45. Section of a 'Symon Fault' in the parish of Malinslee, Coalbrook Dale Coalfield. (Reduced from the restored section of Mr. Scott.)

c. Fire-clay and two seams of poor coal (1 foot each); c¹. Top Coal 4½ feet thick; c¹. Big flint Coal 4 feet. All (5) the regular coal seams down to this level are removed in the centre of the Symon-fault. [The strata within the fault are represented of too uniform thickness. For example, the shales above c vary from 48 to 84 feet in thickness, and the other strata in like proportion.]

by fresh sediments. But in the latter case the Lower Coal-measures with the several seams of coal had been formed before the channel which has cut through and removed so large a breadth and length of them was excavated. This may have been due either to temporary elevation and to subaerial denudation, or to exposure to strong wasting currents. Rolled and worn fragments of coal and of the associated rocks are of frequent occurrence in the overlying strata. Generally the Symon-faults are on a much smaller scale than this, and seem more analogous to the erosion, removal, and rearrangement with which we are so familiar in shallow-water deposits, such as the Bunter Sandstone and the Crag (Vol. I, fig. 119), where the constantly shifting currents have given rise to incessant reconstruction, and false bedding.

Depth of working. It is generally considered that seams of coal less than two feet thick do not pay to work; but this depends on the quality of the coal and the depth. While in the north of England smaller

[1] 'Trans. Geol. Soc.,' 2nd ser., vol. vi. p. 215.
[2] 'Quart. Journ. Geol. Soc.,' vol. xvii. p. 457.

seams than these would not be worked, there is a seam in one of the collieries near Bristol, which, although only 14 inches thick, is, from its value as a smith's coal, worked at a depth of 900 feet. As coal becomes scarcer, small seams will no doubt be more generally worked[1], and the depth to which coal can be profitably wrought may be considerably increased. A few years ago 1000 feet was considered a deep pit; now there are many pits in Somersetshire, Lancashire, and Durham which are worked at depths of from 1500 to 2000 feet. The deepest pits in this country are in the Lancashire coal-field. There is one at Dukinfield (Ashton Moss pit), which has now been carried to the depth of 2850 feet, and another near Wigan is worked at a depth of 2445 feet, at which depth (the mean surface temperature being 49° F.) the temperature of the strata reaches 93° F. The deepest workings were, however, near Charleroi, in Belgium, where they were carried to a depth of 3411 feet, but no working is going on at that depth at present. The practicability of working at greater depths is mainly a question of ventilation. The conclusion arrived at by the Royal Coal Commission was that coal might eventually be profitably worked at a depth of 4000 feet.

Organic Remains of the Carboniferous Series.

The fossils of the Carboniferous Period are broadly divisible into two very distinct groups, namely, the rich marine Fauna of the limestones and shales of the lower division, and the luxuriant land Flora of the upper division or Coal-measures. These, however, are to a certain extent interchangeable; for, occasionally, examples of the Flora appear in the lower division, and the marine Fauna reappears in the upper division.

Protozoa are represented here and there by Sponges, while in many beds Foraminifera swarm. One species deserves attention, from its vast profusion in a stratum of the Mountain-limestone of Northumberland. The unweathered rock is hard and dark-coloured, and the freshly fractured surfaces show no obvious traces of organic remains; but, on weathering, a granular structure becomes apparent, and as the disintegration extends deeper, the rock is reduced to a crumbling mass of small spherical bodies about the size of mustard-seed. Mr. H. B. Brady has determined these to be a Foraminifer, namely *Saccammina*, which he has named *S. Carteri*; and he draws attention to the fact that 'this Palæozoic fossil has its nearest known ally in a species living abundantly on the coast of Norway at a depth of 450 fathoms.' Mr. Brady has also discovered a true

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[1] Many of the thinner seams are, however, broken up and destroyed by the *creep* produced by removal of underlying thicker coals.

Nummulite in beds of this age. Fusulinæ abound in the Carboniferous Limestone of Russia, the United States, and Arctic America; and numerous

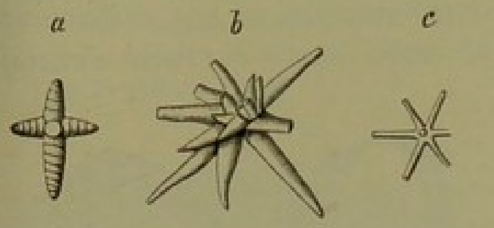

FIG. 46. Highly magnified Spicula of Carboniferous Sponges. (After Hinde.) *a. Holasterella Wrightii. b. Holasterella conferta? c. Astræospongia patina.*

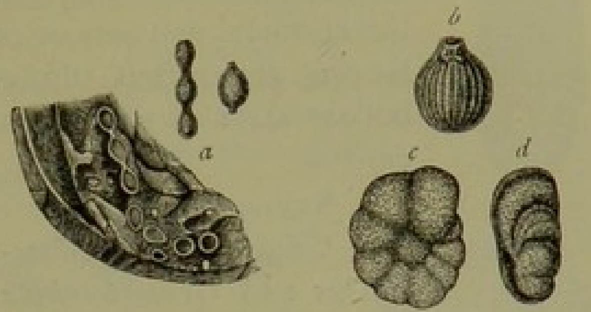

FIG. 47. Carboniferous Foraminifera. *a. Saccammina Carteri*, Brady; nat. size. *b. Lagena Howchiana*, Brady, × 25. *c, d. Endothyra Bowmani*, Phillips, × 25.

other Foraminifera, chiefly of arenaceous structure, are known in the same Formation in Europe and America.

Corals belonging to the genera *Amplexus*, *Lithostrontion*, *Zaphrentis*, *Lonsdalia*, and others, are largely represented. Masses of Lithostrontion have been found nine feet in diameter. The older genera, Favosites and Petraia, have nearly disappeared. Altogether there are 125 species, among the most characteristic of which are the following :—

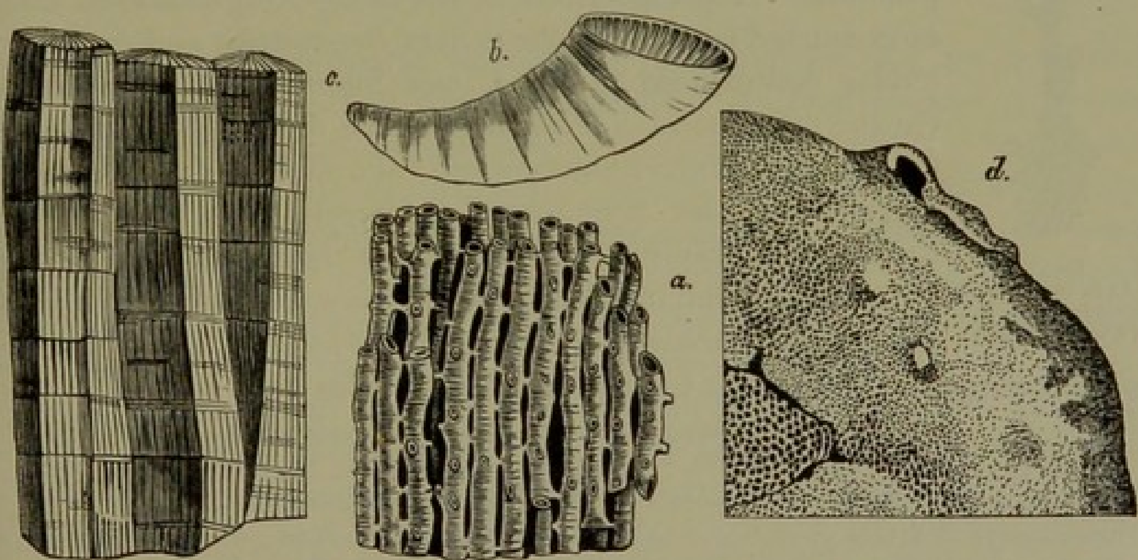

FIG. 48. *a. Syringopora geniculata. b. Zaphrentis Phillipsi. c. Lithostrontion basaltiforme. d. Chætetes septosus.*

Amongst the **Echinodermata**, Crinoids of the genera *Actinocrinus*, *Cyathocrinus*, *Platycrinus*, (*P. lævis*), and *Poteriocrinus* (*P. crassus*) are abundant. The columns and single plates of some species occur in places in such profusion as to constitute a large portion of the limestone itself. The grey crinoidal limestone of Derbyshire, which is largely used as an ornamental marble, owes its pattern to the innumerable sections of these

Crinoids which the polished surfaces exhibit; while other of these limestones owe their ornamentation to the Corals. Where the matrix consists of chert, as sometimes happens in Derbyshire, the crinoidal columns or plates have been often dissolved out, leaving the curious siliceous 'screw-stones' of the district as hollow casts of the stems, and solid casts of their central cavities.

FIG. 49. *Actinocrinus triacontadactylus*, Mill. (After Buckland.)

Amongst other peculiar Crinoids are *Mesoblastus* and *Granatocrinus* (*Pentremites*), genera which are almost special to the Carboniferous period.

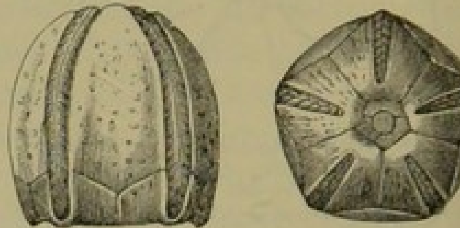

FIG. 49*. *Granatocrinus Derbiensis*, Sby. (After Etheridge and Carpenter.)

Crustacea. Trilobites are now reduced to the genera *Griffithides*, *Phillipsia*, *Brachymetopus*, and *Proëtus*. These are the last of the race; for remains of this class, which are here far from abundant, have not been found in the strata of any later geological period.

The Eurypterida, which were so numerous in the Upper-Silurian and Devonian periods, now also make their last appearance. Representatives of the living King-crabs, an allied race, existed however in the genera *Prestwichia* and *Belinurus*, having commenced in the Upper Silurian with *Neolimulus*. On the other hand, a few genera of the more highly organised Crustaceans (*Anthrapalæmon*, etc.) now make their appearance, representing the Macrourous Decapods, an order to which the lobsters, cray-fish, and shrimps of the present day belong. Of the small bivalved *Entomostraca*, the genera *Beyrichia*, *Leperditia*, *Carbonia*, *Bairdia*, *Estheria*, and *Leaia* are the most common. Among the Carboniferous Crustacea are,—

(C.M., Coal-measures; M.L., Mountain-limestone.)

Bairdia curta, *McCoy*, M.L.	Belinurus trilobitoides, *Buckl.*, C.M.
Beyrichia arcuata, *Bean*, C.M.	Eurypterus Scouleri, *Hibb.*, C.M.
Leaia Leidyi, *Lea*, C.M.	Phillipsia Derbiensis, *Mart.* Pl. II, fig. 15.
Dithyrocaris testudinea, *Scoul.*, C.M.	Griffithides globiceps, *Portl.* Pl. II, fig. 13.
Entomoconchus Scouleri, *McCoy*, M.L.	Brachymetopus ouralicus, *Portl.* Pl. II, fig. 14.

Insect remains are found in the Coal-measures of England, Europe, and America. The Scorpionidæ and the Julidæ are also represented.

The **Molluscoidea** and the **Mollusca** of the Carboniferous period amount to 1053 species. The common species of Polyzoa are *Polypora dendroides*, McCoy, *Ceriopora rhombifera*, Phil., *Fenestella oculata*, McCoy. Brachiopods are still very abundant, the number of species amounting to 160, and they belong, as a rule, to well-marked types. For example, the great *Productus giganteus* is a most characteristic fossil, and sometimes constitutes great part of entire beds of limestone. Species of Productus, Spirifer, Discina, Orbicula, and Rhynchonella are common:—

Productus scabriculus, *Mart.*
Productus semireticulatus, *Mart.* Pl. IV, fig. 9.
Spirifer striatus, *Mart.* Pl. IV, fig. 12.
Spirifer glaber, *Mart.*
Retzia radialis, *Phil.* Pl. IV, fig. 10.
Athyris Roysii, *Lév.* Pl. IV, fig. 11.
Terebratula hastata, *Sby.*
Discina nitida, *Phil.*

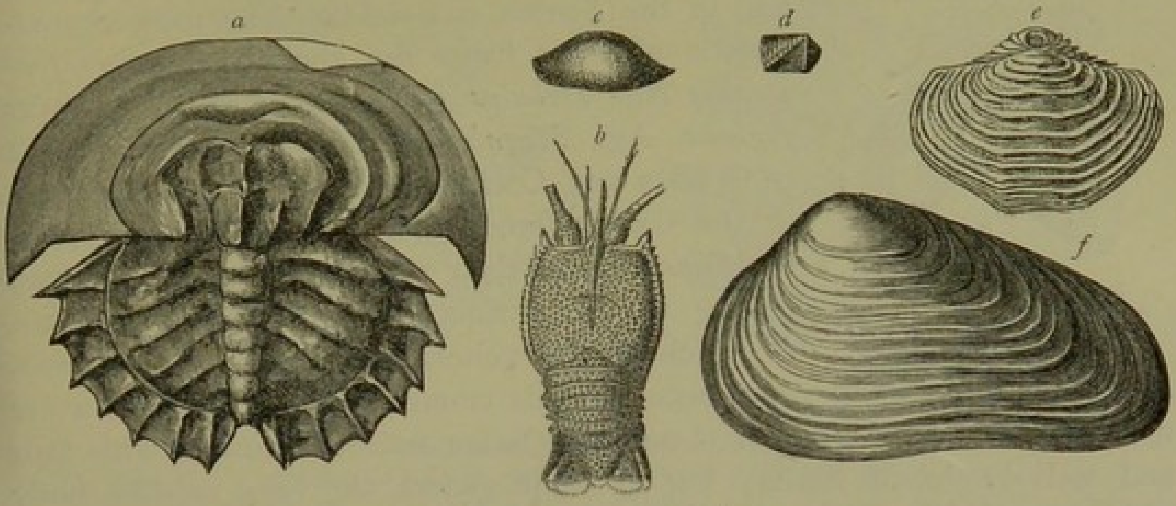

FIG. 50. Carboniferous Fossils.
a. Prestwichia rotundata, Woodw., C.M. *b. Palæocarabus Russellianus*, Woodw., C.M. *c. Leaia Leidyi*, Lea. $\frac{2}{1}$, C.M. *d. Bairdia curta*, McCoy, $\frac{4}{1}$, M.L. *e. Athyris lamellosa*, Lev., $\frac{1}{2}$, M.L. *f. Anthrocosia robusta*, Sby., C.M.

The Lamellibranchiates, so scarce in preceding periods, are now more numerous; the Aviculoid group especially. *Anthracosia* and *Allorisma* are very common Coal-measure genera. Gasteropod shells are well represented by several typical Palæozoic genera, such as the *Macrocheilus*, *Loxonema*, and *Euomphalus*. Of the less exclusively Carboniferous genus Pleurotomaria, the *P. carinata*, Sby., is a common form. The Heteropods and Pteropods are numerous in places, and some of them are of very large size; a common species is the *Bellerophon Urii*, Fleming.

The Cephalopods attain a great development, as many as 154 being found in rocks of this age. *Orthoceras*, so largely developed in Silurian strata, is again abundant, but, with the remarkable Halstatt exception, disappears with the palæozoic series. *Goniatites* are very abundant, and, with the exception of a few species in the Devonian, are peculiar to the Carboniferous period.

Carboniferous Mollusca—

Aviculo-pecten papyraceus, *Goldf.*
Posidonomya Becheri, *Bronn.* Pl. V, fig. 12.
Cardiomorpha oblonga, *Sby.*
Conocardium minax, *Phil.* Pl. V, fig. 13.
Edmondia rudis, *McCoy.* Pl. V, fig. 14.
Porcellia Puzio, *Lév.* Pl. V, fig. 15.
Euomphalus pentangulatus, *Sby.* Pl. V, fig. 16.
Bellerophon Urii, *Flem.*
Goniatites Listeri, *Mart.*
Goniatites sphæricus, *Mart.* Pl. V, fig. 18.
Nautiloceras cariniferum, *Sby.* Pl. V, fig. 17.
Orthoceras cinctum, *Sby.*
Conularia quadrisulcata, *Sby.* Pl. V, fig. 19.
Pleurotomaria carinata, Sby.

Fishes of new types are also abundant; there are no fewer than 353 species. The 'Placoids' of Agassiz attain here their maximum development. The hard palatal teeth and the long fin-spines of these fishes occur in great abundance in some of the limestones, especially those of the North of Ireland. The bright enamelled scales of various 'Ganoid' fishes are also common in some of our central coal-fields, and in the Scotch coal-fields. The most characteristic of these fishes are the *Gyracanthus formosus*, Ag., *Helodus gibberulus*, Ag., *Psammodus porosus*, Ag., *Megalichthys Hibberti*, Ag. Teeth of Orodus and Cochliodus are sometimes common in the Carboniferous Limestone (Fig. 52). *Amphibia* now make their first appearance. They all belong to the extinct order of Labyrinthodonts, of which several genera, such as *Anthracosaurus*, *Loxomma*, and *Keraterpeton*, occur in this country; but other genera are met with abroad. Most of them were Salamandroid animals, with tails and well-developed limbs; but in some genera the long eel-like body appears to have been devoid of limbs. This is the first appearance of the air-breathing vertebrates. The *Dendrerpeton* from the Coal-measures of Nova Scotia is a good type of the old terrestrial Amphibia, analogous to the *Menopoma* of the present day.

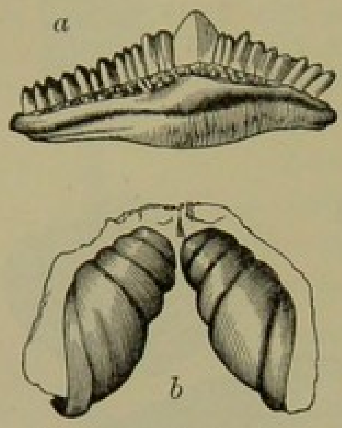

FIG. 51. *a. Orodus cinctus*, Ag. *b. Cochliodus contortus*, Ag.

Plants of the Coal-measures. This remarkable Flora is of the greatest interest, not only on account of the peculiar character of the vegetation, which consists of gigantic Cryptogams, with some Conifers, but also in that this vegetation served to form those abundant beds of coal that contribute so largely to the comfort of mankind, and to the prosperity of this country.

The great bulk of this old vegetation is massed together in a manner that, with a few exceptions in which wood-structure may be detected under the microscope, has destroyed most traces of its vegetable origin. Here and there also on the surface of the coal itself, impressions of the stems and branches of the coal plants, together with portions of mineral-charcoal ('mother-coal' of the miners), are met with. But in the associated shales stray portions of fern fronds, with leaves and fragments of the other plants, are found in vast abundance.

Here and there a few ferns in fructification and some nut-like seeds are found, but these are rare. The palæontologist has too often to depend for his identifications on the evidence of the leaves alone, and of the external and internal structure of such stems and trunks as are found not unfrequently in a sufficiently good state of preservation.

The most marked character of the Carboniferous vegetation is the abundance of Equisetaceous and Lycopodiaceous plants, of large size, and

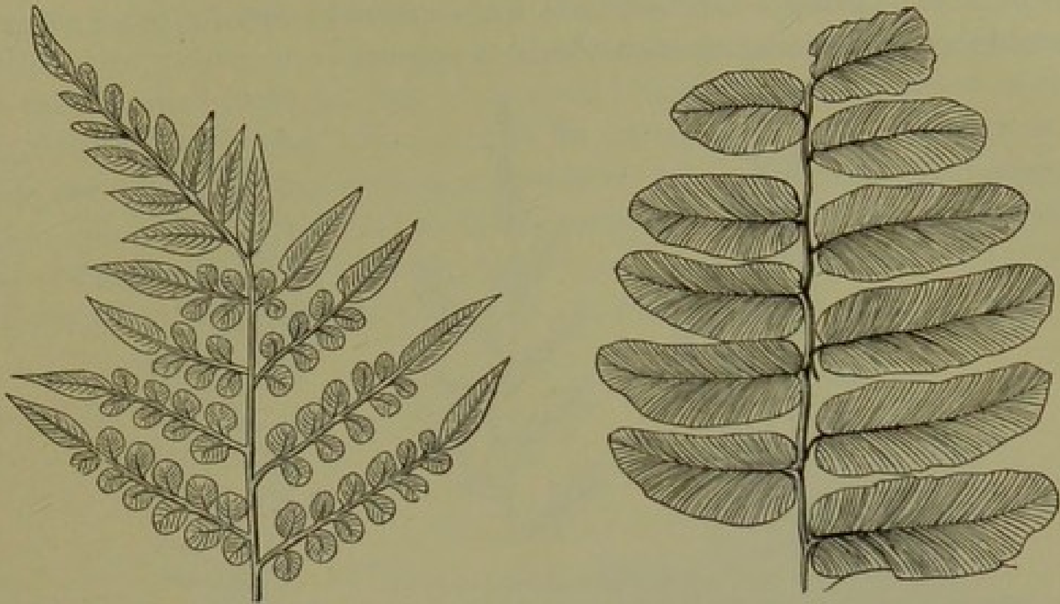

FIG. 52. Ferns of the Coal-measures.
a. Neuropteris Loshii, Brongn. *b. Neuropteris gigantea*, Sternb.

of Ferns. The last include both herbaceous forms, like the majority of

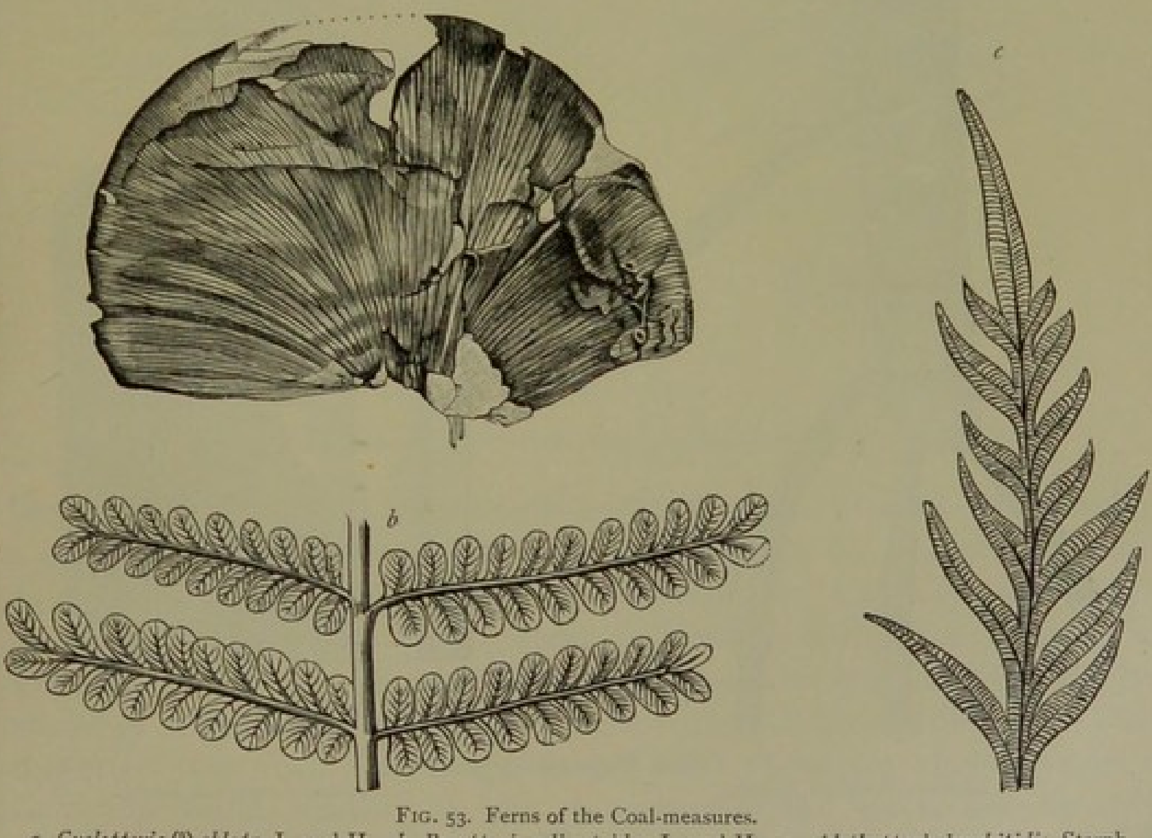

FIG. 53. Ferns of the Coal-measures.
a. Cyclopteris (?) *oblata*, L. and H. *b. Pecopteris adiantoides*, L. and H. *c. Alethopteris lonchitidis*, Sternb.

existing species, and arborescent forms, like the tree-ferns of New Zealand. The former may be divided into three sections:—(1) the *Neuropteridæ*, of which the *N. acuminata*, Schl., which much resembles the *Osmunda* of the present day, may be taken as a type.

(2) The *Pecopteridæ* are the fossil representatives of *Pteris* of the present day; *Alethopteris* (*Pecopteris*, Br.) *lonchitidis*, Sternb., bears a marked resemblance to an existing New-Zealand species.

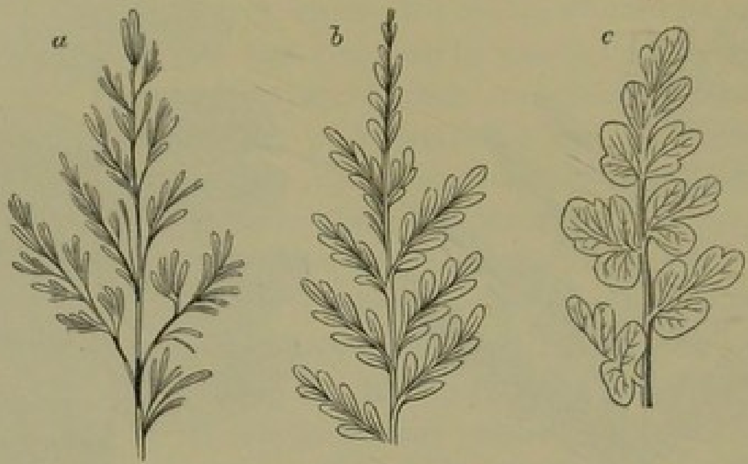

FIG. 54. Carboniferous Ferns.
a. Sphenopteris affinis, L. and H. *b. Sphenopteris obovata*, L. and H. *c. Sphenopteris latifolia*, Brongn.

(3) The *Sphenopteridæ* have more pinnate fronds and narrow leaflets. *Cyclopteris* has more orbicular leaflets and possibly belonged rather to a

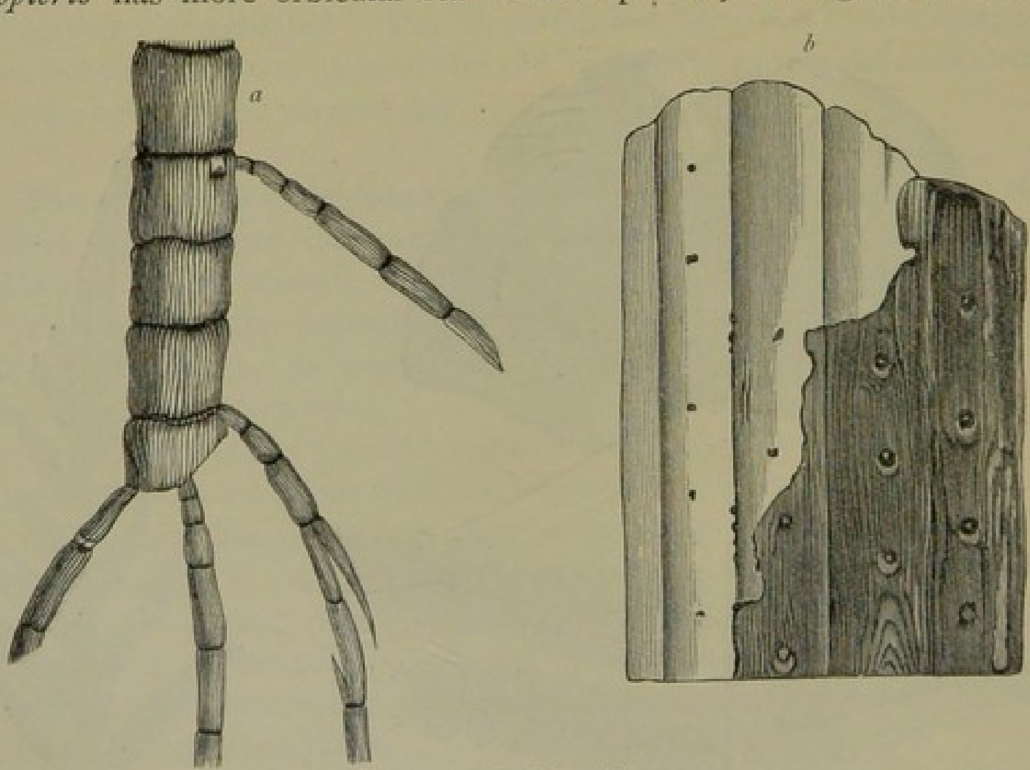

FIG. 55. Carboniferous Trees.
a. Calamites Lindleyi, Sternb. *b. Sigillaria organum*, Sternb.

Salisburian Conifer than to a Fern. The tree-ferns belong mostly to the genera *Caulopteris* and *Palæopteris*.

Imperfect fronds of these ferns occur in thousands in the shales and sandstones of the Coal-measures, the shaley roof especially of some of the coal-seams being literally covered by more or less perfect impressions.

The other forms of this primeval vegetation are of a type far more alien to those of the present day. The *Calamites* much resemble the existing Horse-tails or *Equisetaceæ*; but, instead of being small and reed-like, they formed trees 30 feet or more in height, with a diameter of from 1 to 6 inches or more. Their casts in sandstones, and impressions on shales, are amongst the commonest fossils of the Coal-measures all over the world. They are often found in their erect position of growth in the sandstone beds intercalated with the coal-seams. A well-known instance is that described by Brongniart in the Coal-field of St. Etienne. Sir J. W.

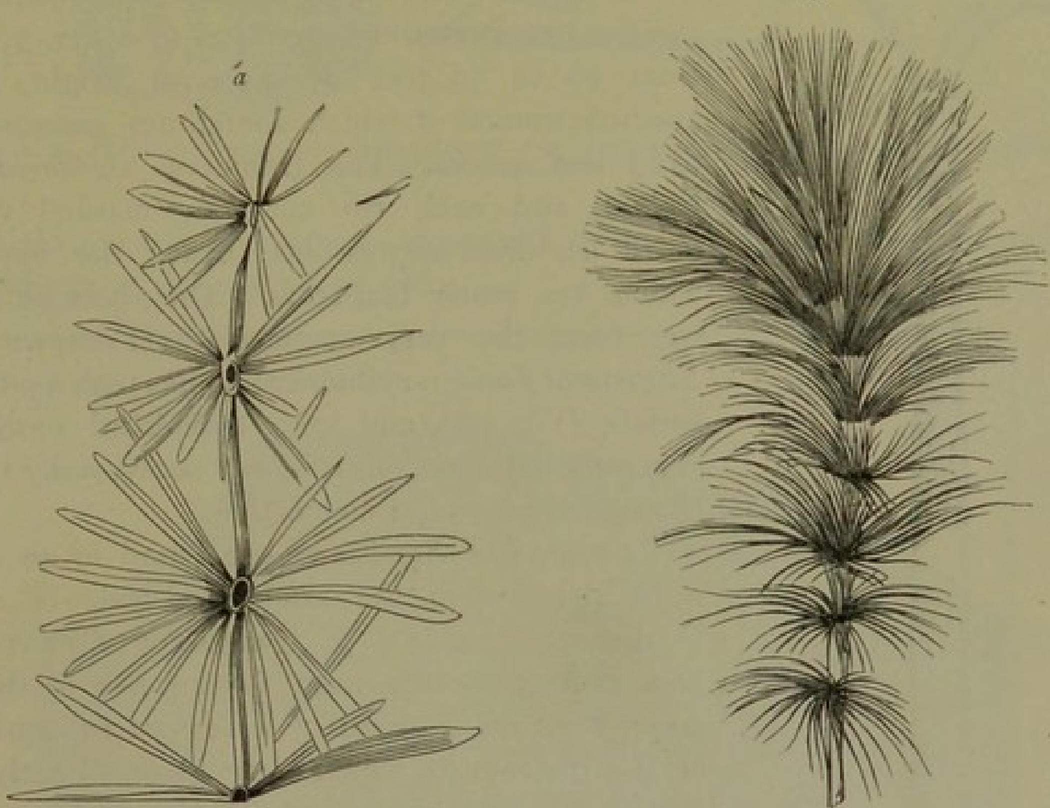

FIG. 56. *a. Asterophyllites equisetiformis*, Schloth. *b. Asterophyllites longifolia*, Brongn.

Dawson describes what appears to have been a thicket of Calamites in a stratum of sandstone near Pictou, and of which the vignette (reduced figure) at the end of this chapter is a specimen. Calamites are easily recognised by the regular flutings and articulations of the stem (Fig. 55, *a*). The furrows are not, however, the external marks of the stem, but interior markings of the cortical envelope or bark. The thick cortical layer is often converted into coal, and is apt to fall off. There are many species of Calamites distinguishable by the characters of the stems and by their foliage; the latter is known under the name of Asterophyllites.

Another gigantic representative of a small existing cryptogamic plant, the Lycopodium or club-moss, is exhibited in the *Lepidodendron* of the

Coal-measures. Its trunks have been found more than a foot in diameter, and the trees must have reached a height of upwards of 50 feet. They are readily recognised by their numerous rhombic or oval scars, indicating the points where the leaves were formerly attached (Fig. 61, *a*). The branches were covered with slender pointed leaves, closely crowded together, and the fructification was carried at the end of the branches in the form of cones or spikes, bearing the closely-packed sporangia (Fig. 62, *b*) and enclosed spores. These cones, or *Lepidostrobi* (Fig. 62, *a*), are very common in some of the ironstone nodules of our coal-fields.

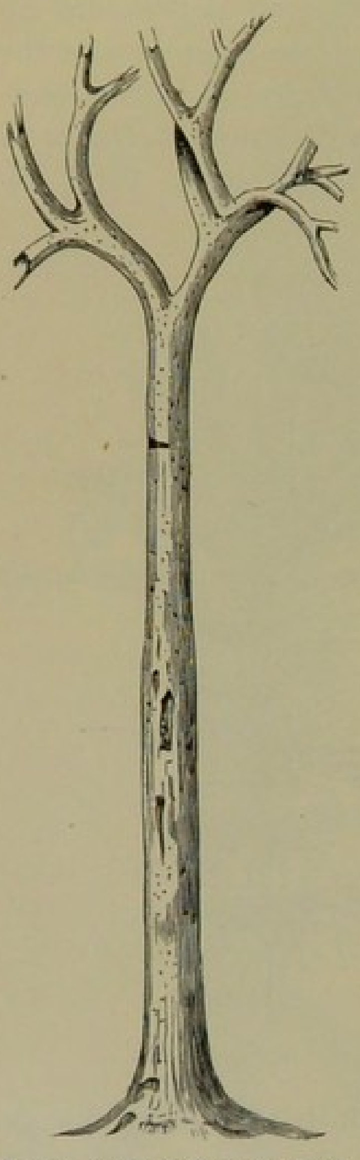

FIG. 57. *Lepidodendron Sternbergi*, Brongn. This tree, which was 49 feet in length and 12½ feet across the branches, was found in the roof of a coal-seam near Newcastle.

Other large and very characteristic plants of the Coal-measures are the *Sigillariæ* (Fig. 55, *b*), from 40 to 50 feet or more in height, the crushed trunks of which sometimes measure 4 to 5 feet across. The trunk of *Sigillaria* is ribbed, and each rib curiously marked with small seal-like impressions (hence the name), which are really leaf-scars. The roots of this tree form the very common fossil known as *Stigmaria ficoides*, cylindrical bodies with a pitted surface (Fig. 58), and long cylindrical rootlets generally flattened, but it is only occasionally that the two are found in connection.

Stumps of *Sigillaria*[1] are found in an upright position in the sandstone beds of the Coal-measures. Sir J. Hawkshaw discovered in a railway-cutting near Bolton five of these stumps within a space of a few yards square, in the position in which they grew. Lately a remarkably fine specimen with the roots entire has been found at Clayton near Bradford, for the sketch of which I am indebted to Mr. W. A. Adamson of Leeds (Fig. 59).

It is said that there are as many as eighty-three species of *Sigillaria*, characterised by variations in the form and position of the leaf-scars, but all ribbed nearly alike. The pitted surface of the *Stigmaria ficoides* shows no traces of fluting, and was long supposed to belong to quite a different plant. Although the distinguishing names are still retained, there

[1] It was in stumps remaining *in situ* in the coal-shales of Nova Scotia that Sir J. W. Dawson discovered the little *Dendrerpeton* and *Hylonomus*, together with land-shells (*Pupa*) and remains of Julidæ (*Xylobia*) and Insects, mixed up with the old rotten wood and mud.

is no longer any doubt that they both belong to the same plant. The foliage of the *Sigillaria* consisted of long linear leaves, which have been described under the name of *Cyperites*; and the fructification has been found to consist of cones packed with sporangia. In all the Lepidodendroids and Sigillarioids the *spiral* arrangement of the scars and pits exists.

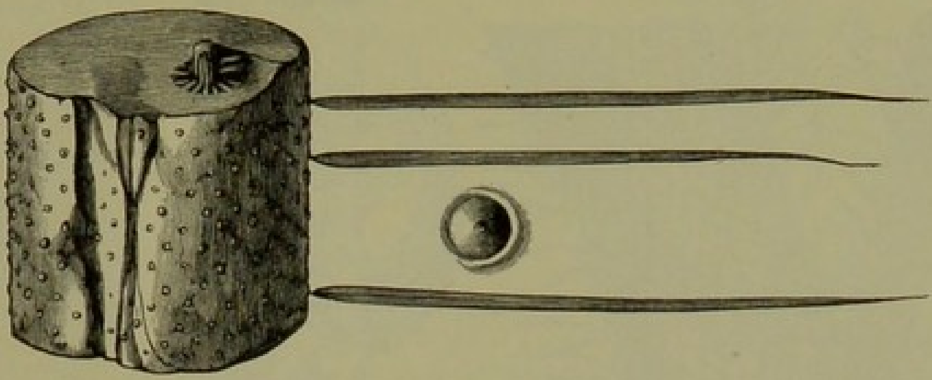

FIG. 58. *Stigmaria ficoides*, showing central woody axis, somewhat out of place (with a few of the rootlets replaced, and an enlarged rootlet-tubercle) in ironstone, Coalbrook Dale.

Sandstone casts of Halonia, supposed to be the fruit-bearing branch of Lepidondron, are often met with.

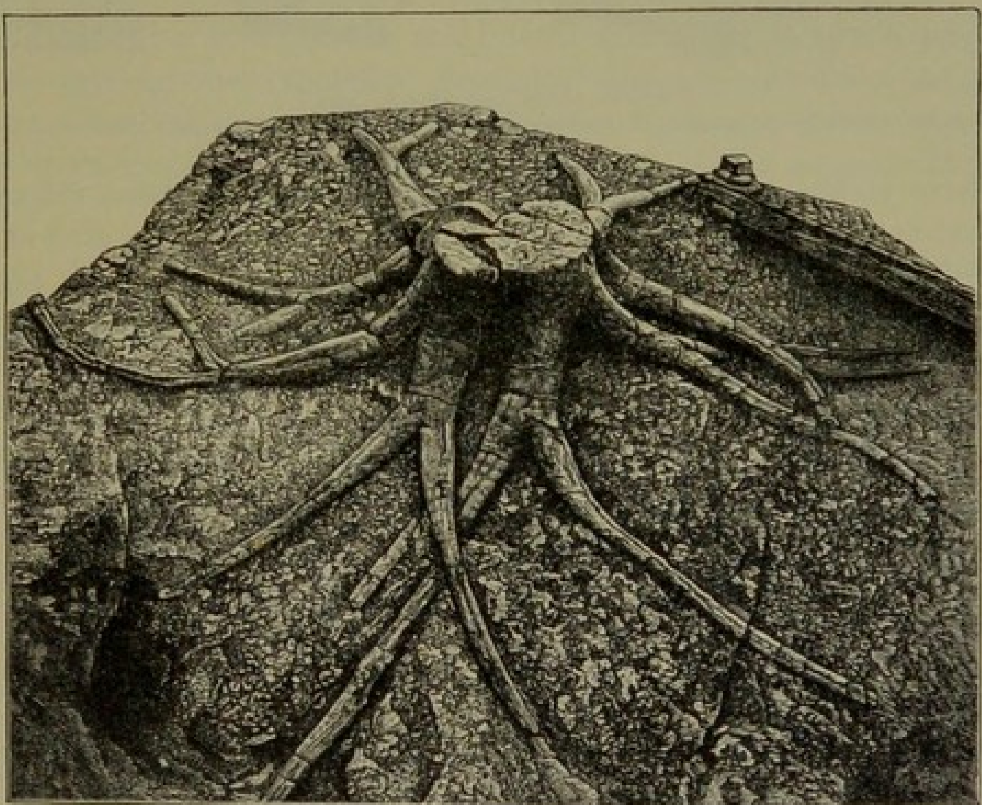

FIG. 59. *Fossil Tree* (*Sigillaria*), *and its roots* (*Stigmaria*) *from the Lower Coal-measures, Clayton near Bradford.* (From a photograph.)
Height of stump, 3 feet 9 inches; diameter, 4 feet 2 inches; length of roots, 8 feet 6 inches to 17 feet; diameter close to stump, 16 inches to 21 inches.

These four families—*Ferns*, *Lepidodendra*, *Calamites*, and *Sigillariæ*—furnish the great bulk of the vegetable remains of the Coal-measures.

They are all cryptogamic plants, belonging to the vascular *Acrogens*, the first three being now represented by ferns, club-mosses, and horse-tails, while the last, though lycopodiaceous, has no living representative.

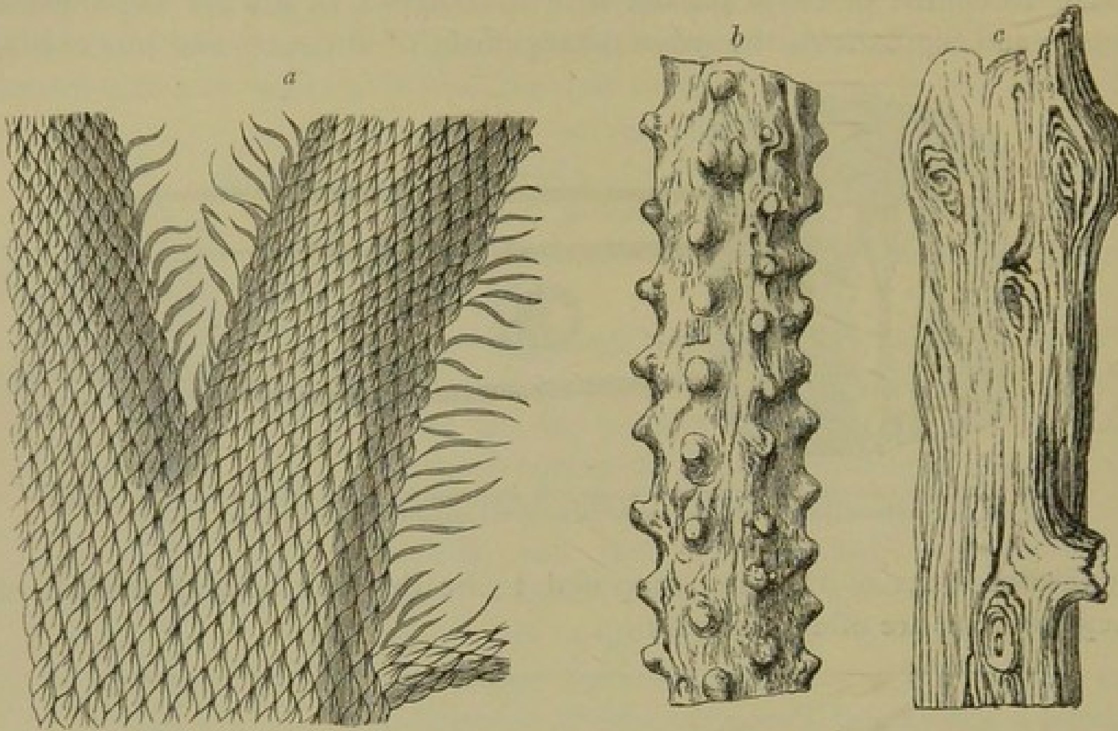

FIG. 60. Other Carboniferous Trees.
a. *Lepidodendron elegans*, Brongn. b. *Halonia regularis*, L. and. H. c. *Dadoxylon Brandlingi*, Endl.

There is, however, evidence that a higher class of plants did exist at the Coal-measure period. Tree-trunks (*Pinites*, *Dadoxylon*, etc.) of great size, with concentric rings of growth, are occasionally met with. Some of the specimens, which are generally found prostrate, must have been magnificent trees. At Granton, near Edinburgh, one was found 6 feet in diameter by 61 feet in length, and another 4 feet in diameter by 70 feet in length. Some of the specimens show, under the microscope, the peculiar punctated structure characteristic of Coniferous wood. They seem to be allied to Araucaria and Eutassa.

There are also found curious fruit-like bodies, provisionally called *Trigonocarpa* (Fig. 61, *c*), which are supposed to be the fruit of some Taxoid Conifers. *Cardiocarpum* (Fig. 61, *d*) is believed to be an extinct form of Gymnosperm.

Hence it is evident that, besides the dense cryptogamic vegetation, there were also in these primeval forests lofty Coniferous trees, which, from their having berries or small nut-like fruit instead of true cones, were probably allied either to the recent yews, or to the deciduous Salisburia—the peculiar Chinese 'Gingko' tree.

The other class of Gymnospermous exogens, namely, the Cycads, is doubtfully represented by a few specimens of uncertain affinities; while of the higher order of the exogens or the angiosperms, such as our own ordinary fruit-bearing trees, there are no traces.

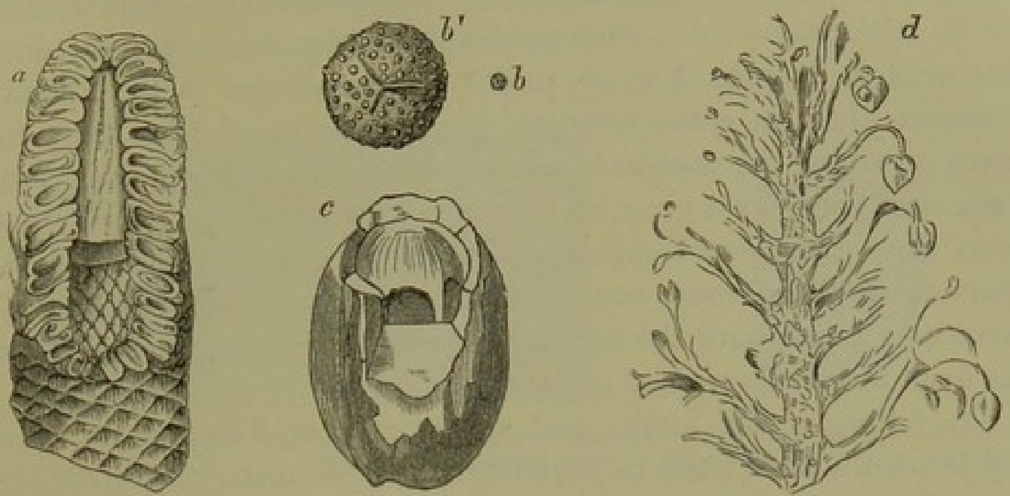

FIG. 61. Seeds and Fruits of Carboniferous Plants.
a. Lepidostrobus ornatus, Schl. *b. Sporangia of Lepidostrobus ornatus*, Schl. *b'.* The same, magnified. *c. Trigonocarpum ovatum*, Lind. and Hut. *d. Cardiocarpum anomalum*, Morr.

The microscope has proved the occurrence of parasitic fungi among Coal-measure plants. One peculiar fungus led Unger to infer the existence of certain Moths of which the caterpillars or grubs are fungus-eating.

It is probable that the low and humid nature of the ground on which the great cryptogamic vegetation flourished was not suited for the growth of other trees, and that the Coal-measures represent rather the marsh growth of the period, than the upland vegetation of the anterior Devonian period[1].

Growth of the Coal Vegetation. The way in which coal-seams have been formed out of this ancient vegetation has been attributed, firstly, to the carrying down, by floods, of vast rafts of uprooted trees, such as are seen on the Mississippi; secondly, to the intermittent subsidence of the land on which the vegetation of the Carboniferous period grew. The latter is now the more generally accepted view, because a considerable number of the tree trunks are found in an erect position; and, more especially, because so many of the coal-seams are found to be underlain by a bed of shale, penetrated in all directions by *Stigmaria ficoides*, a fossil which, as just mentioned, is now determined to have been the roots of of *Sigillariæ* and possibly of *Lepidodendra*. The stems of these plants, passing upwards through the overlying coal-seams (of which they form part), are sometimes met with again in the superincumbent beds, in the form of sandstone casts.

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[1] For a valuable critical examination of the structure of the Carboniferous trees, the student should consult the papers of Dr. W. C. Williamson in the Trans. Roy. Soc. 1870–1884, 'On the Organisation of the Plants of the Coal-Measures.'

The seams of coal are too uniform in thickness, too extensive, and too continuous, to be accounted for by the drifting of wood into an estuary, although some of the smaller seams may have had their origin in this way. There is, at the same time, evidence, in the intercalation of beds containing marine organic remains (Fig. 40, p. 88), such as marine shells, crinoids, and crustaceans, that, in some districts, the sea occupied from time to time the area on which the coal-beds were formed. The inference is, therefore, that the coal vegetation grew on low extensive marshy swamps,—that from time to time these were submerged and covered by the sea,—and that deposits of sand and mud, now changed into sandstones and shales, accumulated over them, until the area was again converted into marsh-lands, on which fresh forests flourished for a time.

The falling of the leaves and spores and the decay of the trees gradually formed a thick mass of peat-like vegetable matter, covered, here and there, with a growth of ferns, in the midst of which rose huge *Sigillaria*, and the more graceful forms of *Lepidodendron* and *Calamites*. From time to time storms and hurricanes prostrated these succulent and reed-like trees, which had their insecure footing in the soft and boggy soil, to be succeeded by a fresh crop of similar vegetation, which from its nature and the character of the climate was in all probability one of very rapid growth and of equally rapid fall and decay.

At the same time we have other evidence of the existence of land-conditions in the remains of amphibian reptiles, land-shells, scorpions, insects, and myriopoda, which could not have lived far from the spot where their remains are found. Allusion has already been made to the land shells found in the interior of fossil tree-trunks in America. This must have resulted when, after a state of repose and a jungle growth of variable duration, the land again began to subside, and became slowly submerged. As the trees died, decayed, and fell, they left stumps of various lengths. The harder woody cylinder with the rind or bark of these stumps stood for a time; while their hollowed-out centres were filled up with the sand or mud which afterwards covered the submerged area, and thus formed those casts of the interior of the trees with the bark converted into coal so common in the Coal-measures.

The small seed-cases (Sporangia) of the Lycopodiaceous and Equisetaceous plants, with their minute spores, also contributed, notwithstanding their diminutive size, by their myriads of numbers, to the formation of our coal-beds. For not only are these sporangia, which are no larger than a mustard-seed, found in isolated crushed specimens, but they also form, with the still more minute spores, parts and indeed whole beds of coal from 1 to 2 feet thick, or more. Such seams of coal are of common occurrence in the Shropshire, Warwickshire, and many other coal-fields. These spores and spore-cases resist decomposition better than ordinary woody fibre; individual specimens of the larger forms are often so well preserved, that they can be readily detected in the coal, even by the naked eye. The following enlarged sections are from figures given by Mr. E. Wethered in a paper 'On the Structure and Origin of Coal Seams[1].'

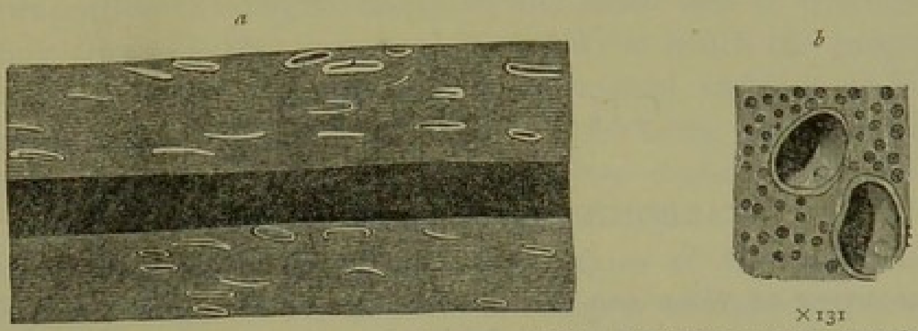
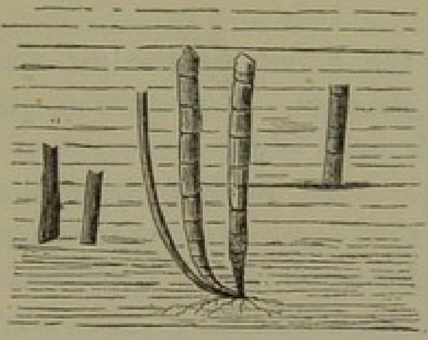


FIG. 62. *a. Vertical section of the Splint-coal, from near Edinburgh, showing a bright layer between two dull ones, with spores confined to the latter. b. Horizontal section of the same seam, showing macrospores and microspores.*

Although woody structure can only be occasionally detected in ordinary coal, it is of common occurrence in some of the Lancashire cannel-coals. Further, the kind of structure is in some cases perfectly determinable. Sometimes it is punctated woody tissue; in others it is scalariform tissue; and in others only cellular tissue. The occurrence of punctated tissue indicates the presence of Coniferæ (that is to say, of cone-bearing trees, like firs, cypresses, etc.); scalariform vessels point to Ferns, as well as to Sigillaria and Lepidodendron.

The variation in the character and quality of the coal-seams is usually accompanied by some variation in the nature of the plants with which they are associated. They all belong to the same groups, but there are local variations in relative proportion and abundance. Altogether 328 species of plants have been found in the British coal-fields.

Calamites in situ, Nova Scotia, p. 107.



[1] 'Journ. Roy. Micros. Soc.' for May 1885.

CHAPTER VIII.

CARBONIFEROUS SERIES (*continued*).

THE COMPOSITION OF WOOD AND COAL. THE GAS IN COAL. RELATIVE VOLUME OF WOOD AND COAL. THE CHEMICAL QUESTIONS. THE CLIMATAL CONDITIONS. THE ATMOSPHERE OF THE COAL PERIOD. WOODY FERMENTATION. THE COAL-FIELDS OF GREAT BRITAIN AND IRELAND; THE CONTINENT AND OTHER PARTS OF THE WORLD: BELGIUM; FRANCE; GERMANY; SPAIN; RUSSIA; ASIA AND AUSTRALIA; AFRICA; NORTH AMERICA; THE ARCTIC REGIONS. DURATION OF OUR COAL-FIELDS.

The Composition of Wood and of Coal. Although it is not difficult, looking at the chemical composition of wood and coal, to realise the fact that our great coal-beds are derived from the primeval forests of this geological period, it is more difficult to indicate the precise measure and manner in which the change from wood to coal was effected [1].

The elements of dry wood—taking the average of a number of woods, such as oak, birch, fir, etc., and omitting the one to two per cent. of ashes—are combined in the following mean proportions :—

1. Carbon (the residue left as charcoal in the burning of wood in close vessels) ...	50·2
2. Hydrogen (the light gas forming with carbon one of the gases existing in coal)	6·2
3. Oxygen (the gas forming with carbon another of the coal gases). Including also generally a small proportion of nitrogen (1 to 2 per cent.)	43·6
	100·0

Wood exposed to the action of the air and moisture is found to undergo great chemical changes. A portion of its carbon combines with oxygen to form carbonic acid, while a portion of oxygen combines with hydrogen to form water. This involves the rapid decay and loss of the wood by oxidisation and slow combustion or eremacausis. If, however, wood be exposed to decay under water where it is protected from the action of the atmosphere, the changes which take place are of a different order and the loss of carbon is less. Nevertheless, the generation of marsh-gas (CH^4), carbonic acid (CO^2), and water which ensues, reduces the relative pro-

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[1] The reader should consult 'Coal,' by Professors Green, Miall, Thorpe, Rücker, and Marshall; and Bischof's 'Chemical and Physical Geology,' vol. i. chap. xv, for further information respecting the geology and chemistry of coal.

portion of oxygen and hydrogen, while that of the carbon remains in excess. Accordingly, the composition of peat in the following table (Col. I) shows a relatively larger proportion of carbon. The next change is to the state of lignite (Col. II), in which there is a further diminution in the proportion of oxygen, and a further small loss of hydrogen. The succeeding change is that into coal (Col. III), in which the proportions of oxygen and hydrogen are still further diminished, and that of the carbon relatively increased, the proportion of the latter being greater in the caking and bituminous coals than in the splint or dry coals. The proportion of carbon attains its maximum in anthracite (Col. V).

The following are the average proportions of the constituent substances at each stage They however are subject to considerable variations.

	I. Peat.	II. Lignite.	III. Splint Coal.	IV. Caking Coal.	V. Anthracite.
Carbon	60·0	68·0	82	87	94·0
Hydrogen	5·8	5·5	5	4	2·5
Oxygen	34·2	26·5	13	9	3·5
	100·0	100·0	100·0	100·0	100·0

It will thus appear that the conversion of wood into coal is due to the liberation of a large proportion of the elements of the wood, which enter into fresh combinations both among themselves and with the constituent gases of the air and water present during the change. The exact mode in which this takes place is yet a question.

The Gas in Coal. A large proportion of the gases generated during the change remain doubtlessly impounded in the coal, and are given off as the pressure is removed in the course of the workings. When coal has been exposed to the air for some time it is found to be full of small microscopic cavities which have probably served as reservoirs for the condensed gases. The quantity contained in this way in coal is sometimes enormous. Jukes says of the Staffordshire coal that some beds are so saturated with gas, that, when cut open, it may be heard oozing from every pore of the coal; and Sir Warington Smyth speaks of coals on the freshly cut surface of which you may set the gas alight with your candle, and it will flash or flicker away to a distance sometimes of a few inches, at others of some feet [1].

If the gas is in very large quantities, a rapid discharge takes place, as if from a blower, the gas being ejected with great violence, and with a sound like that of steam at high pressure from a boiler. Generally, these streams of gas are found to diminish gradually, and then to cease altogether. In some cases, the quantity of gas has however been so large as to necessitate

[1] It is only when mixed with eight to ten parts of atmospheric air that this gas, which burns by itself without explosion, forms the dangerous explosive mixture, the cause of so many frightful accidents.

the closing of the pit, and means have had to be taken to facilitate the escape of the gas on the surface. The author of 'Fossil Fuel' (p. 230), writing in 1841, mentions 'that at a pit not far from Wallsend Church, a four-inch pipe had to be connected at the pit-bottom with an insulated portion of coal strata extending about four acres, and carried up as high as the head-gear, and that from the orifice of this tube, there constantly issued an ignited stream of gas forming a flag of flame, at least eight or more feet in length. . . . . It produced a sound like the roaring of a blast furnace. The immense natural gasometer in which this tremendous agent is collected, supplied the flame at the rate of eleven hogsheads per minute.' This continued for many months.

With the predominant light carburetted hydrogen there also is present a smaller proportion of carbonic acid, together with small proportions of free oxygen and nitrogen.

It is not known in what condition the gas exists in the coal. The quantity is so enormous and in such a state of compression that it must in all probability be either in a liquid or solid state[1]. The objection to the last supposition is that the heat to which it has been subjected at depths so far exceeds the critical point of the gas, that it would not admit of such a change of condition. But although the pressure at which carbonic acid becomes solid is known, that at which marsh-gas undergoes the change has not been ascertained; nor is it known what in these changes is the ratio between the temperature and the pressure. The hydrocarbons form such an excessively variable series—a series ranging, under the ordinary atmospheric pressure, from light gases to liquids and solids—that we can easily conceive that a slight increase of pressure might materially affect their physical conditions, or we may imagine a slight change in composition, such as may be indicated by the presence of some of the associated gases, may have produced the marsh-gas from a hydrocarbon of another type. The point that weighs with me in supposing it to exist in a liquid, if not a solid, form in the coal, is the enormous quantity occluded, and its long and gradual delivery.

Relative volume of Wood and Coal. On the supposition that we are dealing with wood similar to that of the forest-growths of the present day, it is evident that the loss of substance not only in the more gaseous elements of the wood, but also in the carbon during its conversion into coal, must have been very considerable. It has been estimated, for example, that a thickness of 5 feet of the original wood-growth would, by these losses and by pressure, be reduced to 2 feet of ordinary coal, and that for every foot of anthracite coal it would require 8 feet (?) of woody matter, so that the formation of a bed of anthracite 30 feet thick would

[1] From experiments recently made by the 'Gas Explosion' Commission it would seem that the pressure sometimes amounts to 400 lbs. per square inch.

have required a bed of vegetable matter 240 feet thick. There is an evident want of agreement in these estimates. Maclaren has also calculated, with reference to one of the Scotch coalfields, that an acre of coal 3 feet thick is equal to the produce of 1940 acres of forest.

Little importance, however, can be attached to these calculations, as the loss depends entirely upon the way in which the conversion of wood into coal takes place, and on the character of the original wood. Bischof has shown that the change may be effected in four different ways involving very different losses of carbon. But until we are agreed upon what may probably have been the character of the wood, such calculations are of little avail.

The Chemical Questions. The chemical composition of existing woods varies only slightly in the proportion of contained carbon, it being in some woods 48 and in none exceeding 52·5 per cent. The reason of this is that a very large proportion of the wood is composed of woody fibre, which consists essentially of cellulose, and this substance is one of uniform composition whatever may be the character of the wood,—namely, Carbon 44·44, Hydrogen 6·17, Oxygen 49·39 = $C^{12} H^{10} O^{10}$.

Any variation in the chemical composition of wood must therefore depend on the presence of substances the composition of which differs from that of cellulose, such as *Lignin*, *Lignerose*, etc., and it is the presence of these in variable but never in large quantities that causes the slight difference of composition noticed in existing woods. Further, it must be remembered that in the estimates which have been made, the wood only has been taken, excluding the bark and any other parts of the tree or any of the extraneous substances present in many plants. The wood also has been that of Phanerogamic trees alone, which have little relation to the Acrogenous vegetation of the Coal-measures. The data the former afford are by no means in sufficient accordance with the nature of the problem we have under consideration. The number of analyses bearing on the subject is also limited. In the absence of the necessary data, we can only deal with what may be considered the probabilities of the case, but these are not to be overlooked.

	Lignin. (*Payen.*)	Lignerose. (*Payen.*)	Cork. (*Mitscherlich.*)	Lycopod Spores. (*Petersen.*)
Carbon	62·25	67·81	65·73	64·80
Hydrogen	5·93	6·89	8·33	8·73
Oxygen }	31·82	25·30	24·44	20·29
Nitrogen }			1·50	6·18
	100·0	100·0	100·0	100·0

Even if we took at present all plant life, we should have a very different total. The presence of the barks would greatly modify the results. Into these substances *Lignin* and *Lignerose* enter largely; while analyses of cork and Lycopod spores show not only larger proportions of hydrogen and carbon, but also a reduced proportion of oxygen, and the presence sometimes of a considerable proportion of nitrogen.

Again, starch, so common in the stems and roots of many plants, contains a rather larger proportion of carbon than cellulose, its composition being $C^{12}H^9O^9$.

But it is in the gums, resins, mucilage, and sap of a hot-climate and succulent vegetation that we should also look for the analogies of this primeval vegetation. To take for example the following:—

	Nitrogen.	Carbon.	Hydrogen.	Oxygen.
Milky sap of the cow-tree		81·47	11·14	7·39
Caoutchouc		85·88	11·11	3·07
Dammara[1] resin		81·96	11·18	6·86
Plant albumen	15·65	53·74	7·11	23·50

The roots of ferns contain an acid and a resin in which there is a large percentage of carbon, and the leaves and spores of Lycopodiaceous plants contain large proportions of extractive matter and resin with excess of carbon. When we consider therefore the character of the Carboniferous vegetation—its marshy and forced growth, its succulent nature, and its apparently thick barks, we may reasonably admit that the proportion of carbon in the masses of vegetable matter was, in all probability, larger than in the present-day standards, before cited.

The Climatal Conditions. What the peculiar climatal and physical conditions of the time were, which favoured the growth of so special and remarkable a vegetation, has been a matter of much speculation amongst botanists and geologists. We are told that great caution must be employed in predicating from one species the conditions of another, inasmuch as different species of the same genus frequently exist in very different habitats and under almost opposite conditions of moisture and temperature (J. H. Balfour). Thus palms, although generally characteristic of very warm climates, are by no means confined to them, the *Chamærops humilis* extending in Europe to lat. 44 N. and *C. Fortunei* proving hardy in the South of England. Again, some peculiar warm-climate orchids have representatives at the height of twelve to fourteen thousand feet in the Andes.

Fully admitting the force of these observations, the reader must bear in mind that it is in the general character of the Flora, as well as of the Fauna, that the geologist relies for proof of the high temperature of the Carboniferous Period. The forests of that period consisted in greater part of Lycopodiaceous trees, of which we have only diminutive representatives in temperate latitudes, and for the larger forms of which we must go to

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[1] The Conifers of the Carboniferous Period are closely allied to the Araucarian pines and Salisburia.

tropical latitudes. Those even are dwarf compared to their representatives in the Carboniferous period. Again, tree-ferns of all species are also strictly confined to hot and tropical climates, and not a single species is found in cold climates. When, further, we combine this testimony with that furnished by the animal life of the period, the reality of a warm and moist climate at that period becomes still more conclusive. For example, to take only corals, it is well established that no reef-building corals live in waters the temperature of which ever falls below 66° F. This class of corals is confined entirely to hot and tropical seas, and such there can be little doubt must have been the condition of those Carboniferous seas.

From the circumstance, moreover, that a vegetation of a similar character then extended likewise to high northern latitudes, or over some fifty degrees of latitude, it is inferred that the heat was diffused and uniform —possibly more dependent on the central heat of the globe than on the sun's rays. There is reason also to suppose that the atmosphere was more dense and more charged with moisture. It would be difficult to account in any other way for the wonderfully luxuriant growth of the coal-vegetation. Nor is this of itself enough,—it would seem as though the gigantic size of the Lycopodaceæ must have been fostered by other conditions.

The Atmosphere of the Coal Period. The question was raised some years ago by Brongniart, the distinguished French botanist, whether looking at the enormous quantity of carbon locked up during the Carboniferous period, such an abstraction, which could only have been derived from the carbonic acid of the atmosphere, would not have profoundly modified that atmosphere.

At present the atmosphere is composed of twenty-one parts of oxygen to seventy-nine parts of nitrogen by volume. Along with these, there is also about one part of carbonic acid in 2000 parts of air. A larger quantity of this gas would be injurious to animal life. But plants, living mainly by means of the carbonic acid they absorb through their leaves from the atmosphere, can flourish under a much higher charge of it. The gas is decomposed by the plant, which retains the carbon in a solid form, and gives back into the atmosphere the oxygen which forms its other constituent.

It is therefore contended that, as the carbon which now exists in the form of coal was abstracted from the atmosphere by the plants which grew in the Coal-measure period, the atmosphere now contains, apart from other modifications, less carbonic acid than it did at the beginning of the Carboniferous period by something like the amount stored away in the form of coal.

The land population of the Carboniferous period corresponded with these atmospheric conditions. It was confined to a few cold-blooded reptiles of a low order of vitality, a few Insects, Arachnids, and shells.

That plants can, although animals cannot, live in an atmosphere charged with carbonic acid, has been sufficiently proved. It has been shown by experiment that plants placed in an artificial atmosphere of this character, and exposed to the tempered solar rays, suffer in no respect. Not only so, but it was found that at the end of seven days the whole of the carbonic acid had disappeared, and was replaced by oxygen with a certain proportion (one-third) of nitrogen. Other plants exposed under the same conditions to an atmosphere of normal air effected no perceptible change in its volume or composition. The absorption of 431 parts (one-twelfth of the artificial atmosphere) in the one case, and of a quantity that could not have exceeded 0·003 part in the other, in the same interval of time, resulted in a more rapid assimilation and the quicker growth of the plants placed in the artificial atmosphere; and this was due solely to the presence of the excess of carbonic acid. Further, as 292 parts of oxygen were set free, the atmosphere was, on the one hand, relieved of an injurious impurity, and on the other gained, in the liberated oxygen, a gas indispensable to its purity and to the sustenance of animal life.

Woody Fermentation. In addition to the experiments of M. Daubrée mentioned in vol. i. p. 342, some more recent experiments of M. Frémy[1] show that woody fibre (vasculose) and cellulose exposed under pressure to a temperature of 200° to 300°C. become black and brittle, though they retain their organisation and do not fuse, whereas starch, sugar, gums, and chlorophyll become, under pressure and heat, black, brilliant, often fused, and insoluble like coal; and, like coal, leave a coke. The following is the composition of these artificial coals:—

	Carbon.	Hydrogen.	Oxygen.
Coal from starch	68·48	4·68	26·84
„ gum arabic ...	78·78	5·00	16·22

Now as coal consists, for the larger part, of mineral matter having to all appearance undergone partial softening or fusion and showing no organised structure, associated with other parts in which the vegetable structure has been preserved, and even retains not unfrequently the appearance of wood-charcoal, these differences of structure and aspect are possibly to be attributed to the circumstance that this old coal vegetation consisted in large proportion of succulent plants full of mucilaginous and resinous saps. The change into coal was preceded by the fermentation of this vegetable matter into peaty substance with ulmic acid, which further pressure and heat converted into coal.

Ordinary peat probably comes much nearer the standard of the old vegetation than ordinary wood. The former, after decay under water, yields much ulmic acid, wood yields a certain proportion, and lignite very little. If this sort of fermentation goes on in peaty matter, the change to

1 'Comptes Rendus' for 1879, p. 1048.

ulmic acid destroys all trace of vegetable tissue, and the result is a bright inorganic brittle mass, which, under the influence of heat and pressure, would form the bright laminæ such as occur in coal; while the other portions of the coal, either owing to the original composition of the wood or possibly to exposure to the air before becoming submerged, retain more or less traces of their original vegetable structure.

I am therefore led to conclude that the coal-growth was in all probability one of extreme rapidity, and consisted of woods and plants containing a much larger proportion of carbon than any existing forest vegetation.

THE COAL-FIELDS OF EUROPE AND OTHER PARTS OF THE WORLD.

The Coal-fields of Great Britain[1]. We have already noted the number of coal-seams in the more important coal-fields of England. We have now briefly to notice a few of the physical and palæontological features which distinguish some of the several fields, of which there are not less than seventeen.

The coal-field of Newcastle and Durham is one of the oldest worked and most important. It is rich in plant-remains, many other fossils, including some foot-tracks. It is noted for its bituminous or caking coals, of which it sends large supplies to London. The coal-fields of Yorkshire, Nottinghamshire, and Derbyshire are physically one, although partially separated by faults and intervening Permian troughs. In the lower or Gannister beds some of the shale-roofs abound with specimens, mostly much crushed, of *Aviculopecten*, *Goniatites*, *Posidonomya*, etc.; and some beds near Halifax are rich in fish-remains, including species of *Coelacanthus*.

Separated from these eastern fields by the intervening range of the Pennine Chain (Mountain-limestone), but originally connected with them, before the elevation of that range in Permian times, are the deep coal-fields of Lancashire and Cheshire, a large portion of which lie under Triassic strata. The lower (Gannister) beds are here also rich in marine Mollusca and in fish-remains; while in the upper beds the former are rare, and the latter scarce. It contains in places important seams of cannel-coal.

The small coal-field of Ingleton is in similar relation to the eastern coal-fields, and is remarkable for the great fault by which it is bounded on the east, and which brings the Silurian strata up into contact with, and on to the level of, the Coal-measures.

The Cumberland coal-field skirts the coast from Whitehaven to Maryport. It is also much faulted. Northward the strata pass under Permian

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[1] See 'The Coal-fields of Great Britain,' by Prof. Hull; the 'Report of the Royal Coal Commission of 1866;' J. Morris's 'Coal,—its Geological and Geographical Position,' Proc. Geologists' Assoc. Nov. 1861; and Woodward's 'Geology of England and Wales,' 2nd Ed. 1887.

strata; and at Whitehaven they have been followed westward for about two miles under the sea.

There are small coal-fields in Flintshire, Denbighshire, and Anglesea. The former contains a valuable seam of cannel-coal, and in the second fish-remains are common.

The coal-fields of Coalbrookdale and Dudley are closely connected. In them there is a bed of ironstone (Pennystone) remarkable for its remains of marine Mollusca, Polyzoa, Crustacea, and Crinoids. The measures in both are much disturbed; and great masses of basalt (the Rowley Rag of Staffordshire) protrude through them in many places (Vol. I, p. 377).

Another group of coal-fields are those of Warwickshire and Leicestershire. Some of the coal-seams in these districts are composed almost entirely of crushed masses of the small sporangia and spores of Lycopods.

The extensive coal-field of South Wales is noted for its steam-coals and anthracites. The coal-field of Somerset is closely related to it in structure and general characters. The measures in this field are remarkable for the extreme disturbance and curious faulting they have undergone on the flanks of the Mendips (see Plate, Vol. I, p. 260). They contain but little iron-ore and few marine remains. The South-Welsh coal-field, however, is rich in ironstone (Jackstone), and has a variety of marine fossils.

Scotland. The great coal-field of Scotland ranges from the shores of the Firth of Forth across to the valley of the Clyde. The coal is there not confined to the true upper Coal-measures of England, for the shales of the Lower Carboniferous series likewise contain numerous coal-seams of great economical importance (the 'Ell Coal,' etc.). These lower Coal-measures of Scotland are also rich in organic remains. It is in this division that occur the limestone of Burdie House, and the shales of Wardie near Newhaven, so rich in fish-remains, which have been described by Dr. Hibbert and Dr. Traquair. The shales are also remarkable for their numerous rich ironstone beds and bituminous oil-shales. There is also a seam known as the Boghead coal, or Torbane mineral, so valuable for yielding, under different conditions of distillation, mineral oils, naphtha, and paraffin. In some of the liquid products, especially the coal-tars, small portions of aniline are found; and the quantity is now increased by a number of artificial chemical reactions, which lead to the combination of the component gases of the tar with small proportions of nitrogen, and these give rise to those singular compounds, yielding the beautiful colours known as magenta, mauve, solferino, etc., that have during the last few years been introduced as dyes into our textile manufactures. Other combinations give rise to perfumes and other useful substances.

The Carboniferous rocks in Scotland exhibit frequent evidence of contemporaneous volcanic activity,—porphyries, volcanic tuffs, and various greenstones being often interstratified with the limestones and sandstones.

In other cases the strata seem to have been deposited in a curious way between older hills of volcanic origin.

Ireland. A large portion of the centre and south-west of Ireland is occupied by Carboniferous Limestone. But of the upper members of the series, or Coal-measures, very small portions remain, an enormous area having been removed by denudation. The two most important Irish coal-fields are those of Leinster and Tyrone. Like the Scotch Coal-measures, they are distinguished by a number of vertebrate fossils. The largest assemblage in these kingdoms of the remarkable Labyrinthodont amphibians is found in the Coal-measures of county Kilkenny. Prof. Huxley has described several species belonging to eight genera from a single colliery in that district. The smallest of these amphibians must have been from eight to nine inches, and the largest five to six feet, in length. Amongst them is the snake-like *Ophiderpeton*, the salamander-like *Keraterpeton*, and the long-tailed *Urocordylus*.

The Irish coal-fields present, on the whole, many points of analogy with the Scotch coal-fields; and they exhibit in like manner the frequent intrusion of igneous rocks. The Carboniferous Limestone of the North of Ireland is rich in fish-remains; palatal and other teeth of various Elasmobranchs are common in the Armagh limestones, together with remains of various other placoid fishes.

Belgium. The important coal-fields of Liége and Mons range for a distance of eighty miles along the northern flanks of the Ardennes. The measures are of great thickness, and are singularly disturbed and contorted (Vol. I, p. 260, and this Vol. p. 98), being thrown into vertical and zigzag positions, so that the same shaft sometimes passes more than once through the same seam of coal. This coal-field has greater analogy to those of South Wales and Somerset than to any of the other of the British coal-fields in the number and quality of the beds of coal, the great thickness of the Coal-measures, and the character of the disturbance affecting them. In the neighbourhood of Mons the Coal-measures are worked under a great thickness of Cretaceous and Tertiary strata.

The Lower Carboniferous series is well developed (2500 feet) in Belgium, and consists of several great limestone 'massifs,' of which the two most important are the 'Calcaire de Visé,' characterised by *Productus giganteus*, *P. cora*, and the lower division of the 'Calcaire de Tournay,' with *Productus semireticulatus*, *Spirifer mosquensis*, and a large number of other fossils[1]. The two limestones are separated by dolomitic strata. The neighbourhood of Tournay offers many interesting sections of the limestone with overlying Cretaceous strata.

[1] These have been admirably described and figured by M. De Koninck in his 'Recherches sur les Animaux fossiles du Terrain Carbonifère de la Belgique.'

France. Passing under Cretaceous and Tertiary strata, the continuation of the Belgian basin forms the coal-field of the North of France, which ranges by Valenciennes, and has been followed to a point within thirty miles of Calais. In structure, mode of disturbance (Fig. 44, p. 98), and general characteristics the measures are like those of Belgium, and are hidden by an overlie of 400 to 600 feet of Chalk and Tertiary strata. The measures crop out again in a small coal-field near Boulogne; but the coal-seams are few, and the strata are so much disturbed and so full of water that they are worked with difficulty. This district also presents some remarkable cases of inversion. In one shaft the Coal-measures were met with under 900 feet of Carboniferous Limestone, which comes to the surface in the valley at Hardinghen.

Around the great central plateau of France there are a number of detached coal-fields, generally small, with the exception of the important field of St. Étienne, which is fifteen miles long by six miles broad. These coal-fields are geologically of great interest, as they usually rest directly on granite and gneiss without the intervention of Devonian or Silurian strata; while a large proportion of their sandstones are formed of disintegrated granite, with conglomerates and breccias of granite pebbles, fragments, and boulders. At other places the Lower Carboniferous series is represented by anthraciferous sandstones and schists, and thin limestones with *Productus giganteus*, *Euomphalus pentangulatus*, etc.

Prussia. The largest and most important coal-field in Western Europe is that of Saarbrück in the Rhenish Provinces. It has an area of 900 square miles, and it is estimated that the measures have a thickness of above 20,000 feet, extending to a depth of three and a-half miles below the level of the sea. This coal-field is remarkable for having yielded the first remains of Amphibians. They belong to a Labyrinthodont with characters between Batrachians and Saurians—the *Archegosaurus* of Goldfuss. From this coal-field also no fewer than twelve species of Insects, including beetles, grasshoppers or locusts, and ants, have been described. The same fishes, shells, and plants are found in it as in our English coal-fields.

The next most important field is that of Westphalia. It is forty-six miles long, and of great thickness. It is peculiarly arranged in a series of narrow troughs, running parallel with one another, and amounting to fifteen in number (Vol. I, Pl. p. 260). Saxony contains some small coal-basins. There are also small coal-fields in Hanover, and a richer one in Bohemia. In most of these districts the Carboniferous Limestone is either wanting or replaced by schists and grauwacke of variable dimensions, with *Posidonomya Becheri*, *Goniatites sphæricus*, etc., to which succeed thick beds of conglomerates and sandstones (*Flotzleerer Sandstein*).

Russia. The Carboniferous Limestone with *Productus giganteus* and *Fusulina cylindrica* is well developed, and has an extensive range from

Moscow to the Urals and White Sea; but the coal-bearing series is generally wanting in Russia, the only important coal-field being that of Donetz, on the north shores of the Sea of Azof. It is of considerable size, but little of its details is known.

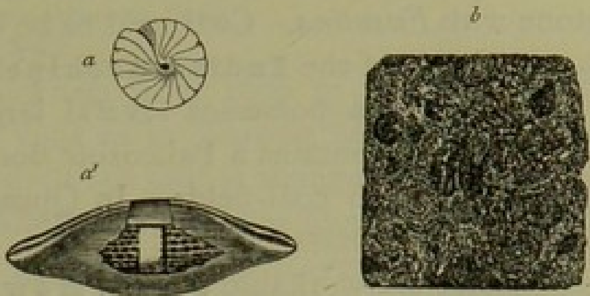

FIG. 63. *a. Fusulina cylindrica*, Fisch. *b. Section of Fusulina limestone*, Japan.

Silesia has a few small but productive coal-fields, one of which is remarkable as containing some of the thickest beds of coal in Europe; there being one seam or group of seams 50 feet thick. The area of the coal-field itself is only about sixteen square miles, but the coal-seams are numerous. Carboniferous Limestone and *Posidonomya* schists underlie the measures.

Spain possesses some true Coal-measures in the northern provinces; they are, however, so little worked that not much is yet known about them. Carboniferous Limestone with *Poteriocrinus*, etc. is found in the N.W. of Spain.

Switzerland. There is a small anthraciferous group in the Western Alps, very much disturbed, and of no economical importance. These Carboniferous beds were at first supposed to be of Liassic age, as they overlie shales with Belemnites; but this was found afterwards to be merely a case of inversion. The strata are highly metamorphosed and schistose.

There are no Coal-measures in Southern Spain, Italy, or Greece.

India. The coal-fields in India are not, like those of Europe, of Carboniferous age, and therefore do not belong to this chapter, unless it be from their economical aspect. On this ground we may mention that there are large tracts of coal-bearing strata which the Indian Geological Survey refer to Triassic age, though from the series being consecutive with older strata beneath, and from the absence of marine remains, some doubt exists as to their exact age. One of the largest coal-fields is that of Raniganj, about 160 miles N.W. of Calcutta; it has an area of 1000 square miles, and the measures are said to be 11,000 feet thick. The Nerbudda coal-field is also important. As in Europe, the strata alternate with shales containing clay-ironstones [1].

China possesses several large coal-fields, apparently belonging to the true Carboniferous period; and coal has been worked there from a very early period, for the use of it was noticed in the thirteenth century by Marco Polo. There would appear also to be coals belonging to Permian if not to

[1] Mr. V. Ball gives an excellent account of the Indian coal-fields (about 55 in number) in his work before quoted.

younger formations, but the information respecting them is insufficient. Carboniferous Limestone with *Orthoceras* and *Productus* also occurs.

Japan has some productive coal-mines, and a Carboniferous limestone with *Fusulina.* Coal, said to be of Carboniferous age, is also found in some islands of the **Indian Archipelago**, including **Borneo.**

Australia possesses several large coal-fields. One of these in New South Wales contains a Palæozoic flora, and is probably of about the same age as our own coal-fields. In Queensland there are other coal-fields of Permian and Triassic age.

There are workable coals in **New Zealand**, but they are of Cretaceo-Tertiary age.

Africa, so far as it is at present known, is not rich in coal. There is none in Northern or Western Africa. On the east coast it has, however, been noticed on the banks of the Zambesi ; and it is worked in strata of Triassic or Permian age in Natal and in the Eastern districts of the Cape Colony. Coal occurs also in the Orange-Free-State and the Transvaal.

North America. The Carboniferous series of North America consists, like that of England, of a lower calcareous or limestone series and an upper coal-bearing series. The American geologists however include the Permian with the Carboniferous and Sub-Carboniferous groups, as the whole forms a continuous and conformable series.

The Sub-Carboniferous Limestones are thin and shaly, and are covered over by extensive pebble-beds and sands, corresponding with our Millstone Grit, to which succeed the coal-bearing strata.

It is remarkable to see how both the animal and vegetable life run parallel with those of Europe. The limestones contain the same profusion and diversity of Crinoids as in Derbyshire ; and, although the species differ, the same genera and families prevail, such as Poteriocrinus, Actinocrinus, Pentremites, and others ; while, amongst the Echinoidea, there is the same aberrant genus, the Archæocidaris. The peculiar columnar coral, *Lithostrontion*, is also, as in England, eminently characteristic of the period.

Brachiopod shells of the genera *Spirifer*, *Productus*, and *Orthis* abound. Trilobites, on the other hand, become, as in England, scarce in the Carboniferous era ; whilst Insect life is more developed.

Amongst fishes, are Ganoids (including *Coelacanthus*) and numerous Cestraciont Sharks with great bony crushing teeth, as in the Irish and Bristol limestones, together with teeth and fin-spines of a species of *Petrodus.*

Amphibians likewise, as in Europe, make their first appearance in the Carboniferous period. In the lower division, however, tracks alone are found—sometimes associated, as in Trias of Cheshire, with ripple-marked and rain-dotted surfaces. The imprints are supposed to be those of a Labyrinthodon amphibian. The limestones are succeeded, as in Europe, by a series of shales and sandstones with seams of coal and bands of iron-stone.

The coal-fields are divided into those of—

1. The Appalachian Basin.
2. The Illinois and Kentucky Basin.
3. The Missouri and Arkansas Basin.
4. The Michigan Basin.

The Coal-measures vary in thickness from 1000 to 14,000 feet, and present much the same variety of coal as in Europe, but with a larger proportion of anthracite; for the bituminous coal is changed into anthracite as it approaches the range of the Alleghanies, on the flanks of which the great coal-fields lie (see Vol. I, p. 412, and Professor Rogers' Report).

The strata contain the usual impressions of leaves and stems; and vegetable tissue has been detected in many of the coals, while in some there is the same assemblage of minute macrospores and microspores of the Cryptogamic trees as in England.

The coal-plants are referable to Lycopods, Ferns, Equicetaceæ, and Conifers; and, as with us, there is some evidence of Algæ and Fungi, and a total absence of Palms and Angiospermous trees. The plants formerly referred to Cycads are more abundant than in Europe; the *Cordaites borassifolia*, Ung. being especially common. The succulent roots of the Sigillaria (*Stigmaria ficoides*) are spread out, as in our coal-fields, in the shales which constituted the soil on which the coal vegetation grew, and now form the 'under-clays' of the coal.

It is further a notable circumstance that not only are all the coal-plants in Europe and America of identical genera, but that a large number of the species are common to the two countries. Out of some 440 European species, no fewer than 176 species are, according to Dana, common to the Coal-measures of America; so that about two-fifths of the total number of species grew at the same time in the Carboniferous forests of the American and European areas. Heer[1] explains this remarkable fact by the circumstance that the flora consisted everywhere chiefly of flowerless plants, the seeds of which, being exceedingly minute and light, would be readily carried to great distances by the wind, as is at present the case with those of Mosses, Lichens, and Ferns. In this way the spores of Cryptogamic plants in the Carboniferous period may have been spread over whole continents, and have traversed wide seas.

It was in the great coal-field of Nova Scotia that Sir William Dawson, as already mentioned, made the interesting discovery of several small Amphibians in the interior of Sigillarian stumps, which had become hollowed out by decay, and were afterwards filled by mud in the marsh or jungle where they stood before their final burial under the deposits that accumulated over them.

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[1] 'The Primæval World of Switzerland.' In the first chapter of this work the reader will find a very interesting account of the Flora of the Coal Period and the formation of Coal.

In one stump the remains of three of these Amphibians, and more than fifty of the small land-shell, the *Pupa*, a living genus common in America and Europe, and a Centipede, were found. Dawson conjectures that the shells were probably the food of the reptiles, for he has found in the stomach of a living American reptile as many as eleven unbroken shells of a small fresh-water shell. Fœcal droppings of the little newt-like creatures, containing undigested relics of Insects, were also there. Other land-shells, *Zonites* and *Dawsonella*, were found in adjacent shales.

This discovery is of much interest, not only as marking the first appearance of air-breathing molluscs, but also as teaching us how many forms of life, which may have existed at former periods, have probably escaped discovery, when we owe to such a chance circumstance the preservation of forms, which to be so found must have been far from rare, and yet elsewhere have left few or no traces of their existence.

The coal-beds of the American measures are numerous, and of considerable thickness, although often very irregular and much disturbed as they approach the Alleghanies. In Pennsylvania they are from 2 to 20 feet thick. Near Mansfield there are several beds having a thickness of 10 feet. The total thickness of the coal-beds in the Pennsylvanian field is 113 feet.

The thickest coals are, however, met with in Nova Scotia. At Pictou the 'main coal' averages 38 feet; another seam, 159 feet lower, is 15½ feet thick; and a third seam, 280 feet still lower, is 12 feet thick.

The extent of the American coal-fields far exceeds that of any country in Europe. The Appalachian basin, for example, is 875 miles long, with an average breadth of 180 miles, or larger than the whole of Great Britain and Ireland together; its area being 157,500 square miles. But the total of the United States fields amounts to the enormous extent of 196,863 square miles. To this has to be added the Canadian and Nova-Scotian fields, which give 12,000 or 14,000 square miles more to the coal-area of North America.

The Arctic Regions. Not only are Carboniferous formations found in the temperate climates of the Old and New Continents, but they are also found in high northern latitudes. Coal-plants of the genera *Pecopteris* and *Sphenopteris* and true Carboniferous *Spiriferi* and *Producti*, with the common Carboniferous coral—*Lithostrontion basaltiforme*—have been found, together with workable beds of coal, in **Melville Island**, and on the shores of the lands at the further extremity of **Baffin's Bay.**

Professor Heer of Zurich has described from **Bear Island**, in lat. 74°50′ N., a group of plants including *Lepidodendron*, the common *Stigmaria ficoides*, and sixteen other species identical in their character with the plants of our own Coal-measures; and this on an island at present covered in great part with perpetual ice and snow, and where not a tree will grow, and only a few dwarf shrubs struggle for existence.

In **Spitzbergen** there are rocks full of corals and shells of Carboniferous age.

It is impossible to resist the inference from the wide range (even to within 10° of the North Pole) of a fauna and flora of this character, that a climate not only of great moisture and considerable warmth, but also of a more uniform character than any at the present day, extended over the northern hemisphere, if not over the larger part of the globe.

Duration of our Coal-fields. Owing to the extensive scale on which the coal-fields of Europe have been worked, and to the constantly increasing rate of consumption, alarm has been felt lest our coal-fields should be approaching exhaustion.

Dr. Buckland, half a century ago, attempted to form an estimate of their duration, and saw no cause for immediate anxiety; but by others a more serious view has been taken.

Professor Hull, in 1860, after a more accurate survey of the coal-fields, came to the conclusion that at the rate of production for that year, there was enough to last for 1,000 years, but that, as the rate of consumption was rapidly increasing, that term would be very much shortened. This increase in the consumption is, of course, a very essential element in the estimate. The then annual rate of consumption for domestic use was estimated by the Royal Commission at one ton per head for the whole population; this only absorbed roughly about one-third of the entire quantity raised. The other two-thirds were used in manufactories, in iron-smelting, and for exportation.

With reference to the rate of increase in these several departments great diversity of opinion exists. At the time Buckland wrote, the consumption was not more than fifty to sixty million tons a year; in 1861 it had reached to 83,500,000 tons; and in 1870 to 110,431,192 tons; and Professor Jevons estimated, supposing it to go on in the same rate of increase, that at the end of 100 years the annual consumption would be 415,000,000 tons, and the supply would be approaching exhaustion.

Under these circumstances, it was considered desirable to establish upon more accurate data the probable quantity of coal yet remaining. For this purpose a Royal Commission was appointed in 1866, on which I had the honour to serve. Among the more important questions concerned with the rate of increase and duration which this Commission had to consider, were (1) waste in consumption, and (2) possible depth of working. The possible depth to which coal may be worked (for there are coals lying at depths of 10,000 or 12,000 feet or more) depends essentially upon the increase of heat which takes place with the depth (which they took on the average at 1° Fahr. for about every 60 feet of depth)[1], and upon ventilation. Taking these points into consideration, the Commission concluded that it would yet be possible to work coal down to a depth of 4000 feet. At present the greatest depth at which coal is worked is under 3000 feet[2], although, as before mentioned, one pit in Belgium has been carried down to 3411 feet.

Endeavours were also made to determine the probable resources of the Coal-measures that pass under, or are supposed to lie under, various newer strata; for, while denudation has removed a very large portion of the Coal-measures, the covering of newer rocks has served to protect other portions of yet unproved extent.

There can be little doubt that all the separate coal-fields of North and Central England, on the one part, and of Southern England and South Wales, on the other, are merely detached fragments of two wide areas, if not indeed of one great whole; because they nowhere, as they would if deposited in separate basins, thin out at their edges; but are all cut off and bounded by faults, or planed off by denudation. There is reason to suppose that Coal-measures originally ranged continuously from the Warwickshire basin to the Northern Counties, interrupted only by

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[1] I have since shown that it is more probably 50 feet or under.

[2] A pit at Ashton Moss in the Manchester Coal-field has recently been sunk to the great depth of 2850 feet.

the hill-ranges of Yorkshire and Derbyshire. In the same way, they ranged over large areas in Scotland and Ireland.

The original wide-spread area of the North-of-England Coal-measures was rent asunder at an early geological period, by the elevation of the Pennine chain, and broken up into the detached portions now forming the separate basins on either side of that chain. Subsequently large portions of the uplifted measures were removed by denudation; while the more deeply-lying portions were again submerged and covered by the newer deposits of Permian and Triassic age extending over parts of Yorkshire and Lancashire.

The result of the inquiry on the part of Sir A. C. Ramsay was to show that, in addition to the 6000 square miles of known coal-fields of Great Britain, there may be in Central and Northern England above 2000 square miles covered by these newer strata, and yet available for future use.

In the same way it is considered highly probable that the great coal-fields resting on the flanks of the Silurian and Devonian strata of South Wales and Somerset were originally connected, and that these Coal-measures are prolonged eastward under the overlying Liassic and Oolitic strata of Somerset, the Chalk Hills of Wiltshire and Oxfordshire, and the Tertiary strata of the lower part of the Thames basin, and reappear in the coal-fields of the north of France and of Belgium. For not only is the axis of the Mendips on the prolongation the same line of disturbance as that of the Ardennes (Vol. I, p. 260), but the Coal-measures of the separate basins of South Wales, Somerset, and Belgium are alike lithologically and palæontologically, as well as in physical structure. There is, therefore, reason to believe that there may be coal-basins underneath the newer Cretaceous and Tertiary strata of the South of England, and that, owing to the thinning out of the Jurassic and Triassic series, they may be within from 1000 to 2000 feet of the surface; but the extent of these basins can only be determined by experience.

Taking all these points, excepting the last, into consideration, the Commissioners came to the conclusion that at the then (1871) annual rate of consumption there was coal enough to last 1273 years; but, with the rapidly increasing rate of consumption, this term would be reduced to a period differently estimated, according to the value of the various contingencies, of which different estimates were formed, of from 324 to 433 years. This, however, involves regular increments more or less progressive for which considerable latitude must be allowed[1].

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[1] The reader will find an excellent summary on this important question in Sir W. W. Smyth's 'Coal and Coal Mining,' ed. of 1886, pp. 244–257.

CHAPTER IX.

THE PERMIAN SERIES.

General Characters of the Series. Its Divisions. The Lower Division. Character of the Beds. The Old Range of the Malverns. The Basement Breccia and Conglomerates. Ramsay's Suggested Ice-Action. The Upper Division. The Flora. The Fauna; Mollusca; Corals; Polyzoa; Fishes; Amphibians and Lizard (?). Poverty of the Fauna. Foreign Equivalents: France; Germany; Russia; North America; India; Australia; South Africa. A Triassic Flora and Carboniferous Fauna. The Boulder-beds of India, Australia, and South Africa: referred to a Glacial Origin. Need of Corroborative Evidence.

General Characters. There is one other group of strata belonging to the Palæozoic period so far as its palæontological relations are concerned; but in its physical and lithological characters it might appear to belong to the base of the Secondary series, and to this it was originally assigned. As the Carboniferous series is underlain by one set of red rocks, —the Old Red Sandstone,—so it is overlain by others, which for long were grouped as one under the head of the New Red Sandstone.

It was found, however, by Sedgwick and Phillips, that the fossils of the lower portion of this series, in the North of England, were all of Carboniferous or Palæozoic type, and quite different from those met with in the upper division; whilst, in most instances, the strata reposed unconformably on the Coal-measures, showing a break in continuity of a very marked character,—the Coal-measures themselves having been upraised

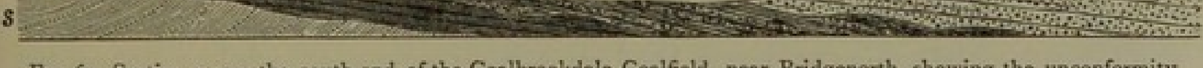

Fig. 64. Section across the south end of the Coalbrookdale Coalfield, near Bridgenorth, showing the unconformity between the Carboniferous and Permian, and between the Permian and Trias. (Reduced from the Geol. Survey.)
o. New Red Sandstone. p. Permian. q. Coal-measure. s. Old Red Sandstone..

and partly denuded before the superincumbent strata were formed. These strata were therefore separated from the New Red or Trias and grouped with the Palæozoic series.

Sir Roderick Murchison followed these beds into Russia, and finding them largely developed in the province of Perm, in Southern Russia, he applied to this geological series the term 'Permian.'

The Permian series consists of two divisions, as under,—

	English type.	German type.
1.	a. Upper Red Marls and Sandstones with gypsum	Zechstein.
	b. Magnesian Limestone and Marl-slate	
2.	Lower Red Marls, Sandstones, Breccias, and Conglomerates	Roth-liegende.

The Lower Division of the Permian is well developed in Staffordshire, Warwickshire, and Worcestershire, and extends thence northwards through Cheshire and Lancashire to Dumfries, and southward to the Malverns. It consists in the Midland Counties of red marls, and of red, purple, and white sandstones, with subordinate seams of calcareous conglomerate. To these succeed a coarse red breccia surmounted by another set of similar red marls and sandstones—the whole almost entirely unfossiliferous, with the exception of the remains of a tree in the lower 'Breccia,'—of fragments of Lepidodendron and Calamites in a sandstone near Exhall,—of silicified coniferous wood at Allesly,—and of Labyrinthodont remains in the red sandstone near Kenilworth. The total thickness of this division is about 1500 feet.

In the Midland Counties the breccia attains a thickness of 450 feet, which is reduced to 200 feet as it trends southward. It consists of angular and subangular fragments of purple Cambrian grits from the Longmynds, of Silurian quartzites, slates, felstones and greenstones, and of Caradoc sandstone from the country between the Longmynds and Chirbury. Consequently, the rock fragments, which vary in size from small hand-specimens to blocks two, three, and even four feet in diameter, seem to have travelled from thirty to forty-five miles from the parent rocks. They are roughly stratified, and imbedded in a red marly matrix. This breccia appears at Enville, the Clent hills, Stagbury hill near Stockport, the Abberley hills, and at Haffield near the southern end of the Malverns.

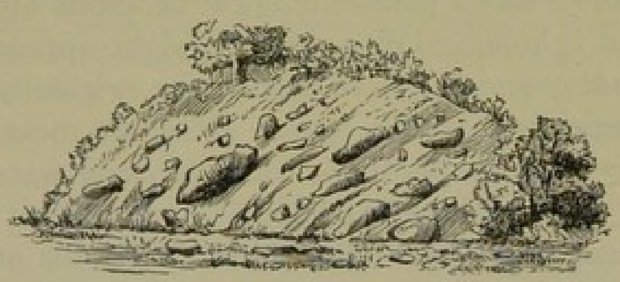

FIG. 65. *Section of stratified Permian Breccia.* Ramsay.

It is probable that the old Palæozoic axis of the Malvern Hills formed the boundary of a mountainous land stretching westward, while a depressed area eastward was occupied by a sea, along the coast-line of which the breccias and conglomerates of the Permian originated, while in the deeper sea further eastward, red marls and sands were being synchronously deposited. Not only were the older rocks of the Malvern and Abberley hills then above the waters, but a large portion of the Coal-measures of Central England had also emerged, and were exposed to the wasting power of the Permian seas.

Suggested Ice-action. But the special point of interest connected with this breccia is, that a certain number of the angular or subangular rock-fragments have the flattened sides so characteristic of glacier-fragments of existing moraines, and are also sometimes polished and finely grooved and striated, like the stones of the present Alpine glaciers. Round pebbles are exceedingly rare. On these grounds Sir A. Ramsay[1] inferred that even at this far distant period, glacial conditions may for a time have prevailed. The character of the organic remains and the physical conditions of the Permian generally, however, are hardly in harmony with this conclusion.

The evidence in all the collateral phenomena must be strongly corroborative before so startling a conclusion can be accepted, and it must be proved that the striation on the pebbles admits of no other explanation. It should be shown also that the blocks had, as in glacial deposits, been dropped and imbedded in the finer matrix in a way incompatible with water-action; that the surfaces of the rocks *in situ* have been planed down, grooved, and polished, as rocks now are by the passage over them of glacier-ice; and that the accompanying marine fauna consists, to a certain extent though with several possible exceptions, of genera or families of northern types, while the land fauna and flora should be in keeping with the general conditions. But we know of no glaciated land-surfaces of Permian dates in Europe, while the fauna, though scanty, is of the same type as that which flourished during the older Palæozoic times, and the flora consists of genera mostly identical with those of the preceding warm Carboniferous period.

With respect to the striation of the pebbles, of which there is no doubt, there are three ways in which striæ may be produced without glacial action. 1. In breccias and conglomerates, extreme compression has often resulted in the indentation of the pebbles in contact together, so that even hard quartzites and flint have in this way small irregular pits drilled on their surface. Such being the case, if a slight shifting of the mass took place during compression, it is easy to conceive that either short striæ or an indentation prolonged into a scratch may have been produced; and this is apparently the way in which the striation of the more or less rounded and polished fragments of limestone in the red Triassic conglomerate met with in the Severn Tunnel has been effected[2]. 2. If from any disturbance or tilting of the strata before they were consolidated the component fragments of a breccia should have slid, as in a mass of concrete, over one another, it would have resulted, when under sufficient pressure, in their striation. 3. But a more common and probable cause appears to me to be the previous faulting of the strata from which the fragments

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[1] 'Quart. Journ. Geol. Soc.,' vol. xi. p. 185.

[2] Professor Sollas, 'Proc. Geol. Assoc. for 1881,' p. 79.

were derived. Faulting is usually attended by extreme lateral pressure, the result of which is the formation of slickenside surfaces often strongly striated, and when the movements have been repeated, as they sometimes have been, in different directions (see Vol. I, p. 254), they simulate very closely glacial striation. During those great disturbances which preceded Permian times, the Carboniferous and Devonian strata were extensively faulted and denuded. A denudation that would raze strata traversed by a number of these slickenside surfaces, and re-deposit the fragments after a short interval of time, which is usually the case with breccias, and therefore before they had undergone sufficient wear to remove the original striation, would necessarily contain a number of these slickensided fragments having flat surfaces and showing striation; and when the slickensides had been very near together, a fragment might show striation on both surfaces. In the red grits of the Devonian strata on the coast of North Devon there are slickenside surfaces *in situ*, presenting grooves and striæ extending many feet in length, but the fact that they follow very closely the general dip of the rocks, which are highly inclined, and not the direction ice would have taken on an open hill-side, is sufficient to show, independently of other circumstances, that the striæ were not due to ice-action. To such a case as this, the striation of the fragments in the Permian breccia may possibly be ascribed.

Ramsay justly remarks on the difficulty of supposing that ordinary marine currents could have moved blocks to such distances from the parent rocks without much greater wear and rounding; and objects to what may be termed waves of translation, in consequence of the absence of proof. But although proof in full degree is wanting, we have in the sea-waves caused by earthquakes, which have from time to time desolated the coasts of Western South America, South-western Europe, and the islands of the Indian seas (Vol. I, p. 221), minor evidence of the transporting power of such bodies of water. We have only to look at the Holmfirth flood, to the bursting of ice-dams in the valleys of the Alps and Himalayas, to see to how great a distance blocks may be transported, and that without losing their angularity. The great power of moving water in the transport of large blocks has also been demonstrated by the calculations of Mr. Hopkins (see Vol. I, p. 83). At the same time it is evident from the facts above mentioned, and from others to be presently mentioned in other parts of the world (many of which supplement the evidence wanting here), that the subject is one for serious consideration.

The Upper or Zechstein Division of the Permian is well exhibited in Durham, where it is very fossiliferous[1] and immediately overlies

[1] See Prof. King's 'Monograph of the Permian Fossils,' Palæontographical Society for 1849; and the several papers by Mr. J. W. Kirkby in 'Quart. Journ. Geol. Soc.'

the Carboniferous rocks. The thickness of the strata, which consist of red marls and sandstones and of light-coloured magnesian limestones, is there about 800 feet. At some places a peculiar change in the structure of the limestone has taken place, leading to the formation of cellular or honey-combed beds, or else to a globular, botryoidal, crystalline, and radiated re-arrangement of the rock itself. This is very conspicuous on the coast of Durham, where the cliffs in places seem formed of irregular piles like large cannon-balls. At Ripon the carbonate of lime has separated out in concretionary masses, leaving a matrix of magnesian sand and marl. At Bolsover, Anston, and Mansfield the magnesian limestone forms massive beds used for building-stones. As the Permian ranges southward, the calcareous zone of Durham and Yorkshire dies out; and in the neighbourhood of Manchester the series is only represented by red marls and sandstones. The furthest point south where the magnesian limestone occurs is Nottingham.

Organic Remains. With respect to the fauna and flora of the Permian strata, which in this country are confined chiefly to the upper division, they continue to present the same types of life as are found in the underlying Palæozoic strata, notwithstanding the importance in places of the physical break between them.

Plants. Although there are no coal-beds, or at least little deserving the name, twenty-six species of plants belonging to Carboniferous genera and families still survived. For example, there are species of *Calamites*, *Lepidodendron*, *Sphenopteris*, *Neuropteris*, and *Cyclopteris*. Of the great Carboniferous *Sigillariæ*, however, there are in England no certain traces. They seem to have altogether passed away. Amongst the Cycads are Noeggerathia (*N. expansa*). New Conifers appear, such as Ullmania (*U. selaginoides*) and Walchia (*W. piniformis*), which are very characteristic of the Permian throughout Europe. There are also found seed-like bodies,—Cardiocarpa,—which by some palæontologists are considered to be the fruit of Cycadaceous, and, by others, of Taxodiaceous trees.

The fauna shows the same relative poverty as the flora, there being in this country only 203 species against the 1088 species of the Carboniferous period. More than half of these are Brachiopoda and Mollusca, of which the most characteristic species are *Productus horridus* (Pl. IV, fig. 15), *Spirifera alata* (Pl. IV, fig. 13), *Camarophoria Schlotheimi* (Pl. IV, fig. 14), *Bakewellia antiqua*, *Avicula speluncaria*, and *Pleurophorus costatus* (Pl. V, fig. 21).

Whereas in the Carboniferous series there are 144 species of Actinozoa or Corals, there are only five known in the Permian strata. Nor are there many *Polyzoa*, though some species are very abundant and characteristic, such as *Fenestella retiformis* and *Acanthocladia anceps*. So also the *Cephalopoda*, abundant (175 species) in the Carboniferous strata, have only one representative (Nautilus) in the Permian.

Trilobites, which we have traced in diminishing numbers through the Devonian and Carboniferous formations, do not appear in the Permian deposits.

Among the Permian Crustacea, *Prosoponiscus* is peculiar; *Bairdia plebeia*, Reuss, is common, also *Kirkbya permiana*, Jones, in some places; and *Estheria* occurs in some beds in France, Germany, and Russia. Foraminifera abound in the limestones of Durham and the Wetterau,—a characteristic form is *Trochammina pusilla*, Geinitz.

The Fishes of the Permian amount in England to twenty-three species, and on the Continent number as many as forty species. They are very characteristic, and all belong to the groups of Palæozoic fishes having heterocercal or unequally lobed tails. The genera are the same as those found in the Carboniferous strata, but the species are all distinct. A ready way of distinguishing the Carboniferous species of Palæoniscus from

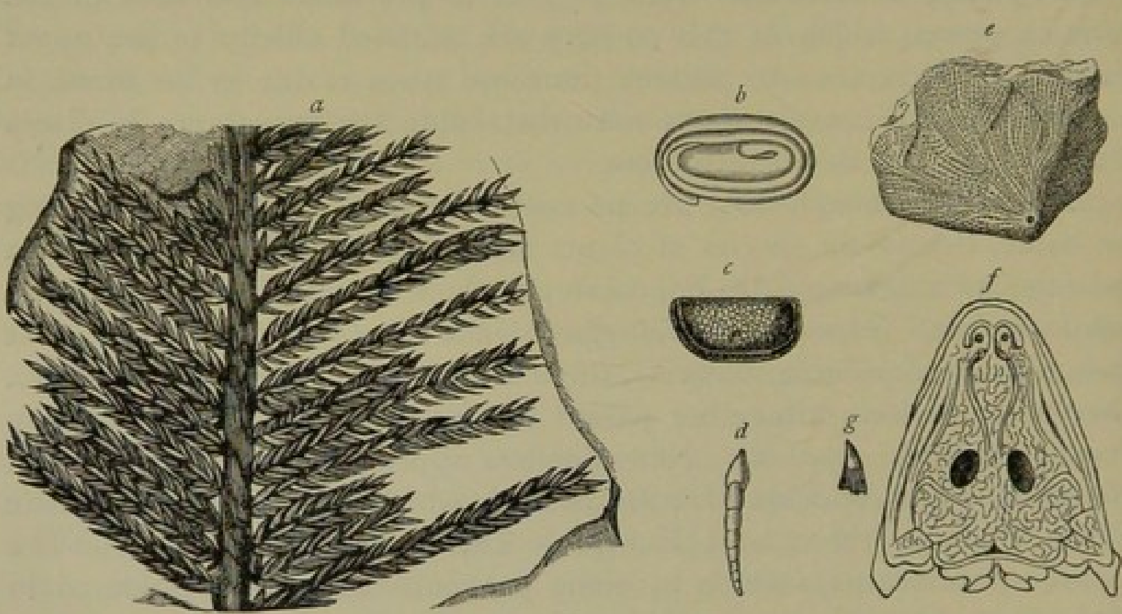

FIG. 66. Various Permian Fossils.

a. Walchia hypnoides, Brongn. *b. Kirkbya Permiana*, Jones, $\frac{12}{1}$. *c. Trochammina pusilla* (Geintiz) × 12. *d. Dentalina communis*, D'Orb. (*D. Permiana*, Jones) × 15. *e. Fenestella retiformis*, Schloth. *f. Skull of Labyrinthodon Jægeri*, Owen. *g. Tooth of Labyrinthodon pachygnathus*, Owen.

the Permian species, is that in the former the scales have usually smooth edges, whereas in the Permian species the scales are generally punctated and serrated.

These fishes constitute one of the most interesting features of the Permian fauna. Like the fishes of the Old Red Sandstone, they occur only in particular beds, and then often in great abundance, as though they had been suddenly killed and entombed. In England they are found in the upper beds of the Magnesian-limestone of Durham, and in the Marl-slate at its base.

The *Labyrinthodont Amphibia*, which first appeared in the Coal-measures, now become more numerous. Their remains are not uncommon in the sandstones near Warwick and Kenilworth. Some of the reptilian footprints in the Permian sandstones of Dumfriesshire are also referred to Labyrinthodonts, but no part of the skeleton has been there found. Some reptilian remains (Protorosaurus) of the Permian formation are, however, of a higher order or type, being more nearly allied to the Monitors of the present day.

There is thus in these Permian strata a very poor and somewhat dwarfed fauna compared with the varied and abundant forms of life which characterised the Silurian, Devonian, and Carboniferous periods; but, although seemingly in a state of decadence, there is still a persistence of forms, which links it to that of the Palæozoic period. With the Permian strata these forms altogether pass away and are lost. Subsequently we meet with new orders and new conditions; for another great and widespread physical disturbance of the Palæozoic strata took place at the close of this period, entirely altering the geographical and hydrographical conditions of the surface; and by the time fresh strata were being deposited a complete revolution in the fauna and flora of the old lands and seas of this part of the world had taken place.

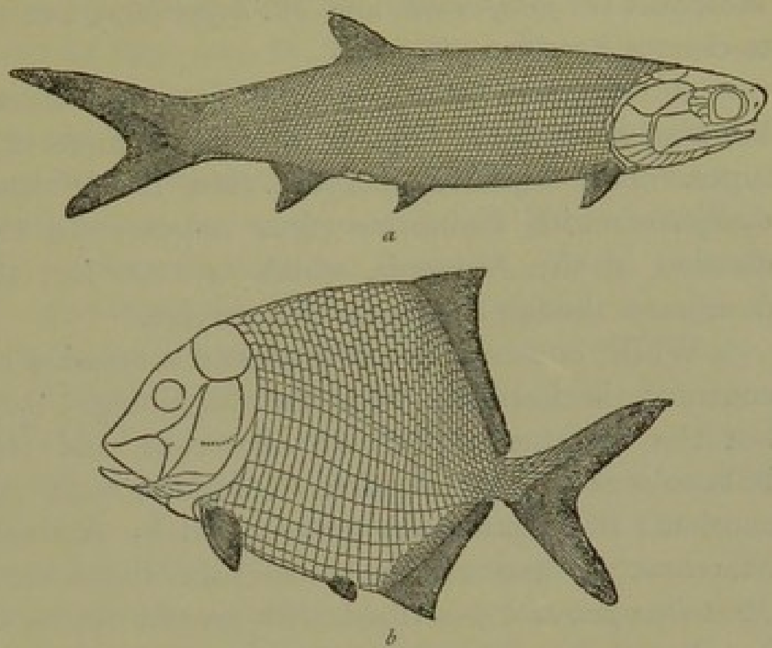

FIG. 67. *a. Palæoniscus macropomus*, Ag. (After Traquair.) *b. Platysomus striatus*, Ag. (After Traquair.)

FOREIGN EQUIVALENTS.

France. The want of stratigraphical sequence between the Coal-measures and the Permian is less apparent in France, where they are connected by passage-beds. So little marked is the break in some places that the lower beds of the Permian are by many geologists held to form a third or upper division of the Carboniferous series, and to this period are referred the upper and less productive Coal-measures of some of the small coal-fields of Central France. The Permian is very fully developed in Eastern France and the Vosges. In the latter district it constitutes part of the

'Grès des Vosges' of Elie de Beaumont, though the upper beds of the original group are now placed with the variegated sandstone (Grès bigarré) of the Trias, the lower felspathic conglomerates alone being considered to be of Permian age. In all these strata, however, fossils are rare, and limited to insufficient plant-remains. The Permian is more fossiliferous and better developed in the typical locality of the neighbourhood of Autun[1]. It there consists, as a whole, of beds of sandstone alternating with bituminous shales, and a few subordinate beds of dolomitic limestone. The lower division, which is about 500 feet thick, contains an abundance of ferns of Carboniferous species, together with conifers of the genus Walchia (*W. piniformis* and *W. hypnoides*), but with little else in the flora to denote Permian affinities.

A middle division, which is 1000 feet thick, presents more marked Permian characters. The flora loses its more characteristic Carboniferous types. The Sigillariæ become rare, the Walchiæ more numerous, and *Callipteris* with *Calamites gigas* appear. In the upper or 'Bog-head' division of the Autunois, which is 1600 feet thick, Permian plants are dominant, though Sigillariæ still survive.

While, however, the flora shows successive changes, the fauna, on the contrary, is Permian from the beginning. Reptilian remains are few, but the remains of fish are numerous, and include several species of Palæoniscus (*P. Blainvillei*, *P. Voltzii*, etc.), Amblypterus, and Pleuracanthus; the reptiles are represented by Actinodon, Enchyrosaurus, and Stereorachis, and the Salamandroid Batrachians by the curious little *Protriton petrolei*, described, with several others, by M. Gaudry[2].

Permian strata are again met with in the south of France; Lodève in the Hérault is a classic locality for Permian plants, which include species of Ullmannia, Walchia, Gingophyllum, Alethopteris, Callepteris, etc. Remains of the Aphelosaurus and Labyrinthodont footprints also occur.

Germany. Here the break between the Coal-measures and the Permian, or the Dyas[3], as it is more frequently called in Germany, is again well marked. The Rothliegende sets in with conglomerates, red sandstones, and bituminous shales, to which succeed the gypsiferous marls and sandstones, with bands of dolomitic limestones, of the Zechstein. The Rothliegende is very largely developed (6000 to 7000 feet) in Bavaria, with enormous masses of conglomerates, composed of fragments of granitic rocks, gneisses, mica-schists, quartzites, etc. The Permians are also largely de-

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[1] M. E. Roche, 'Bull. Soc. Géol. France,' 3rd ser., vol. viii. p. 196.

[2] 'Bull. Soc. Géol. France,' 3rd ser., vol. vii. p. 299; iv. p. 270.

[3] For a full account of the relations of the Permian to the Formations above and below it, and of the use of the term 'Dyas,' the reader should consult the Rev. A. Irving's paper 'On the Classification of the European Rocks known as Permian and Trias;' Geol. Mag. 1882.

veloped in the Hartz, in Saxony, Thuringia, Bohemia, and Moravia. In the neighbourhood of Mansfeld (Upper Saxony) the Rothliegende and the Zechstein present their most typical characters.

Organic remains are generally scarce in the Rothliegende, and are confined chiefly to plants. The Calamites, Sphenopteris, Neuropteris, and Noeggerathia of the Coal-measures, but of different species, still survive, with Lepidodendron, which is rare, but the Sigillaria and Stigmaria have here disappeared, and are replaced by the characteristic Walchia (*W. piniformis*) and Ullmannia (*U. Bronni*), with a Permian Calamites (*C. gigas*). A remarkable feature among the plant-remains is the number and size of the silicified trunks of tree-ferns (Tubicaulis), together with trunks of conifers, also silicified, three to four feet in diameter. The bituminous shales, which sometimes occur at the base of the Rothliegende, contain ganoid fishes of the genera Palæoniscus, Platysomus, Amblypterus (*A. macropterus*), and amphibian remains, including the Archegosaurus (*A. Decheni*). Some of these shales are worked as a fuel (Brandschiefer).

The Zechstein is far richer in organic remains, which include species of Productus (*P. horridus*), Spirifer (*S. undulatus*), Gervillia, Avicula, Pecten, Camarophoria, etc., together with the characteristic Polyzoan, *Fenestella retiformis*. The well-known Kupfer-Schiefer, near the base of the Zechstein, is remarkable for the extraordinary abundance of fish-remains of the genera named above, together with which are a few of the rare *Proterosaurus Speneri*. It is in beds of this age in Bohemia that Dr. Fritsch, of Prague, has discovered a most remarkable series of amphibian remains. He has already described[1] forty-seven new species, belonging to sixteen genera, amongst the most abundant of which are *Branchiosaurus*, *Melanerpeton*, *Ophiderpeton*, *Microbrachis*, *Dendrerpeton*, and *Chelydosaurus*. Most of these amphibians have broad frog-like heads (Fig. 66) and long salamander-like bodies, and are covered with sculptured scutes. Others are lizard-like amphibians, while some are snake-like in their form. Some of the groups show labyrinthic structure in their teeth, others are devoid of it. They were mostly creatures of small size.

The Zechstein of Germany is also remarkable for its stores of Gypsum and Rock-salt. Amongst other places, they are largely worked at Stassfurt in Saxony, where the beds have been followed to a depth of about 1300 feet without reaching the base. The lowest bed consists of rock-salt alternating with thin seams of anhydrite; to these succeed a mass of impure rock-salt 200 feet thick, with chloride of magnesium, and seams of a treble sulphate of lime, magnesia, and potash (*Polyhaylite*). Overlying this is 100

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[1] 'Fauna der Gaskohle und der Kalksteine der Permformation Böhmens,' von Dr. Ant. Fritsch.

feet of rock-salt alternating with beds of sulphate of magnesia (*Kieserite*). These are succeeded by thin beds of red marl alternating with rock-salt, and a double sulphate of potash and magnesia (*Kainite*), with a very soluble double chloride of magnesium and potassium (*Carnallite*), together 150 feet thick. Some of the upper marls contain seams of *Tachnydrite*, a chloride of calcium and magnesium, also very soluble, together with nodules of Boracite ($Mg. BO^4$). The interest of the deposit is, that we here have the more deliquescent salts of the ancient seas, such as the chlorides and sulphates of potash, magnesia, and lime, which have usually escaped with the retreating waters before precipitation, just as is done artificially in salines where the mother liquor containing the more soluble sulphates and

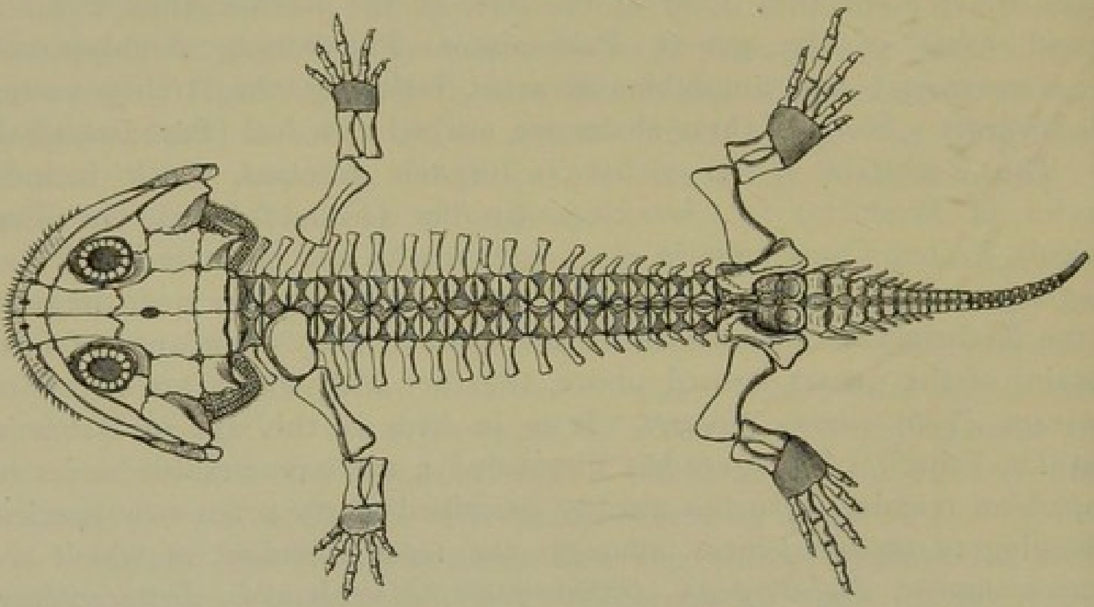

FIG. 68. *Restoration of Branchiosaurus salamandroides by Dr. A. Fritsch*, $\frac{2}{1}$. From the Permian of Bohemia.

chlorides is poured off immediately after the precipitation of the chloride of sodium; whereas at Stassfurt there has been a general evaporation and precipitation apparently of the whole of the salts in the water, with the exception, possibly, of some small residue of soluble bromides and iodides. The proportion of potash salts is remarkable (see Vol. I, p. 108).

The wonderful mass of rock-salt (3769 feet thick) traversed by the artesian boring at Sperenberg near Berlin belongs, it is supposed, to beds of this age.

In connection with the Permian period in Germany, the great eruptions of porphyritic and felsitic rocks which then took place require notice. They welled out at successive times, forming more or less massive contemporaneous sheets, often broken through by later eruptions.

Russia. The Permian strata extend over a very large portion of Eastern Russia. The lower beds consist of red sandstones, variegated marls, conglomerates, and a few limestones, with thin seams of coal. This division contains, as in Germany, a land flora consisting of species of Pecopteris, Calamites, Odontopteris, Cyclopteris, etc., together with a few marine shells of the genera Productus, Strophalosia, Gervillia, Camarophoria, etc. The Zechstein consists chiefly of gypsiferous clays and marls, limestones, and rock-salt. Plants are still common, but a marine fauna with *Productus horridus*, *Camarophoria Schlotheimi*, etc., predominates. Remains of fishes (Palæoniscus) and Labyrinthodonts are also present. It is in this upper division also that the great deposits of malachite, azurite, and other copper minerals are found. They are associated with the remains of plants; the origin of them has been described before (Vol. I, p. 354).

North America. The American geologists divide the Carboniferous series into three periods:—

1. The Permian.
2. The Carboniferous, including the Coal-measures.
3. The Sub-Carboniferous.

There is no apparent stratigraphical break between the Coal-measures and the Permian series. The latter represents rather the closing era of the Carboniferous period; it was a time of decline for Palæozoic life, and of transition towards a new phase in geological history (Dana). Nor does the double or Dyas division exist in America.

The Permian strata there consist of limestones, red and greenish sandstones, grey marls, gypsums, and conglomerates. Both fauna and flora are very poor; a large proportion of them are common to the Carboniferous beds below. Nevertheless, amongst the Mollusca there are species of Pleurophorus and Bakewellia; while it has recently been found that some twenty-five to thirty per cent. of the plants are the same as those of the Permians of Europe; and in the Permian of Illinois, Texas, and New Mexico, there have just been discovered and described by Cope and Marsh sixteen species of fishes, seven amphibians, and twenty-eight true reptiles. It is stated by Le Conte[1] that the amphibians of the Coal-measures and Permian, and the reptiles of the latter, are of remarkably generalised types,—the one connecting together fishes, amphibians, and reptiles, and the other amphibians, reptiles, and mammals.

India. The Gondwána series, which rests unconformably on unfossiliferous metamorphic rocks probably of Silurian age, ranges upwards without break to the Cretaceous period, representing therefore in time the series of rocks from the Carboniferous to the Jurassic inclusive. Owing, however, to the rarity, or entire absence, of marine fossils in the Lower Gondwánas (the Panchet, Damúda, Tálchir beds), it has been a matter of much difficulty to establish a correlation with their European equivalents.

[1] 'Elements of Geology,' Appendix, p. 416, edit. of 1886.

The flora is abundant, and, on the whole, of a distinctly European Triassic and Jurassic type, but from the circumstances—that these beds are overlain by others also with Triassic reptiles and fishes (Hyperodapedon and Ceratodus),—that in the Salt-Range[1] Conularia and Productus have recently been found in beds of the same geological age as the Tálchirs of the Peninsula,—and that the Damúda flora is associated in Australia with a Palæozoic fauna, the authors of the '*Geology of India*' have come to the conclusion that the Damúda and Tálchir formations are, notwithstanding their Mesozoic flora, most probably the equivalents of the Permian of Europe[2]. Dr. W. T. Blanford, who carefully notices the curious alternations in the Gondwána flora, considers it hopeless to classify these deposits by plant evidence (which is often the only evidence) alone[3].

A noticeable feature connected with the Tálchir formation, which consists of fine shales and soft sandstones, is that in places boulders of metamorphic rocks of large size are found in it. In the upper part of this formation are some coal-seams and plants, species of the following genera being the most common,—*Glossopteris, Gangamopteris, Schizoneura, Noeggerathiopsis, Voltzia*, (*V. heterophylla*)[4].

The overlying Damúda series, which is the great coal-formation of India, consists of sandstones and shales with coal-beds. The only animal remains yet met with are an Estheria and two Labyrinthodonts. The flora contains, in addition to species of the genera just named, species of *Pterophyllum*, *Anomozamites*, *Sagenopteris*, *Sphenopteris*, etc., which are Jurassic genera in Europe.

Australia. While the Lower-Carboniferous strata of New South Wales contain plants and a molluscan fauna common to European Carboniferous times, the Upper Measures, which contain, on the contrary, a Mesozoic flora with a Palæozoic fauna, are considered to be of Permian age. This division consists of conglomerates and sandstones with Noeggerathiopsis, Glossopteris, Gangamopteris, Sphenopteris, Phyllotheca, etc., with species of Spirifer, Conularia, Fenestella, etc. To these succeed the Hawkesbury sandstone with another remarkable set of boulders; and then the shales and sandstones of the Wianamatta series, of which the flora is also Mesozoic, while the fishes have Permian affinities. The Australian geologists limit the Permian to the Upper Coal-series, and place the other beds, with doubt, in the Trias. But Dr. Blanford, looking at the analogy of the flora, and at certain physical conditions, to be described presently, considers them as the equivalent of the Tálchir and Damúda beds of India.

South Africa. In South Africa, Palæozoic rocks containing a flora

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[1] 'Records of the Geol. Survey of India, vol. xix. pt. i. p. 22.

[2] *Op. cit.*, pp. xiv, xvi, and 102.

[3] 'Report Brit. Assoc. for 1884.'

[4] This is a characteristic European Triassic species.

allied to the Devonian and Carboniferous flora of Europe are succeeded unconformably by the Ecca and Karoo beds. Like the Gondwána series of India, the Karoo beds have a long continuous range upwards, through which a flora of the same Mesozoic type prevails; and the fossils of the collateral Formation of Uitenhage show Jurassic affinities, though the Reptiles have Triassic alliances. Nevertheless, the exact equivalents of these beds in time with the European formations are yet far from settled. Of the fossils of the Ecca beds little is known, except that in places they contain abundant wood and plant remains. The relation of these groups is closer to the Indian and Australian series than to those of Europe[1], and some of them are therefore thought to be of Permian age.

The Ecca beds consist of 3000 feet of hard blue shales, alternating with variegated and rippled sandstones, and a few layers of nodular limestones, intercalated in which is a central division of 500 feet of conglomerate beds. At the base of the Karoo series, along the Orange River, there is another group known as the Olive Shales and conglomerates 2300 feet thick. The shales contain reptilian bones and plant remains, and some coal on the Vaal. How far these two groups may be synchronous seems uncertain; they both contain some remarkable boulder-beds.

The whole of the Karoo formation has, by some geologists, been referred to the Trias, but Dr. Blanford questions[2] whether the lower or Koonap division should not be included in the Permian. All that has been at present determined with respect to the plants of the Ecca beds, is that some are referable to *Glossopteris*, while in the Karoo beds there are, besides *Glossopteris*, a fern nearly akin to Gangamopteris and a Phyllotheca-like stem. He remarks on the close similarity of the plants to those from the Damúdas of India and the Upper Newcastle beds of Australia, and sees therefore no good reason for refusing to admit that the lower groups of the Karoo may be of the same Permian age.

These facts have given rise to a question of great interest, as to the existence at this period of a vast Indo-Austral-African continent over which extended a rich cycadaceous vegetation of a character very similar to that which at a later time (Triassic and Jurassic) established itself throughout Europe. It is evident either that such was the case or that the Carboniferous fauna survived to a later period in that eastern area than in Europe; the general distribution of the fauna during the preceding and succeeding periods is in favour of the former view.

Boulder-Beds. It has also been pointed out that the relation in time of these Indian, Australian, and African formations would appear

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[1] Professors Tate and Rupert Jones, 'Quart. Journ. Geol. Soc.,' vol. xxiii. pp. 139 and 142: W. Stow, *Ibid.*, vol. xxvii. p. 497.

[2] *Ibid.*, vol. xxxi. p. 530, and 'Brit. Assoc. Proc. for 1884.'

to be confirmed by certain very exceptional and very remarkable physical features.

Amongst the shales and fine sandstones at the base,—though sometimes occurring higher,—of the Tálchir group, the lowest member of the Gondwána system of India, are numbers of pebbles and boulders, rolled and more or less rounded, and varying in size from small fragments to blocks fifteen feet in diameter[1]. They consist of rocks foreign to the locality, and transported from a distance of some miles. Dr. Blanford suggests that they were first rounded by torrents and then transported down rivers by ground-ice, and points out that, as they usually are embedded in a smooth silt finely stratified, they could not have been carried down by rapid streams and currents, for any such as could have moved the boulders would have swept away the surrounding silty matrix. A still more remarkable instance has been discovered in the same Tálchir beds in the neighbourhood of the Godavery, where Dr. Oldham exhumed 'large masses of foreign and transported rocks, the surface of which was polished as perfectly as marble by a lapidary—this polished surface being beautifully scored and furrowed in parallel and straight lines, precisely similar to the scoring, furrowing, and polishing which rocks carried down by glaciers and ground-ice are so well-known to exhibit. And, further, the hard Vindhyan limestone on which this Tálchir boulder-bed was laid, was also found to be scored in long parallel lines wherever the upper surface was freshly exposed by the recent removal of the overlying rocks[2]'.

More recently another group of boulder-bearing strata has been described by Mr. Wynne in the Salt-Range. The conglomerates are there made up of boulders, often of enormous size, imbedded in a dark shale, intermixed with gravel and coarse sand. They consist of various granites, syenites, and other crystalline rocks, mixed in a most irregular way. A great number of the pebbles and boulders are striated as though by ice-action. From the circumstance that the speckled-sandstones which contain the boulder-beds overlie the *Neobolus-beds*, referred by Dr. Waagen to the Lower Carboniferous, and underlie the *Productus-limestone* and *Fusulina-beds*, the former of which he has shown on the evidence of its fossils to be of Permian age, while he assigns the latter to the uppermost horizon of the Coal-measures,—it is probable that these beds are of the same age as the Tálchirs of the Peninsula[3].

The 'Hawkesbury sandstone' of Sydney, which is about 1000 feet thick, contains subordinate shales and pebble-beds. It is 'full' of false-bedding, showing it to have been deposited in waters of no great depth,

[1] 'Manual of the Geology of India,' vol. i. pp. xxxvi and 110.

[2] 'On the Age and Correlation of the Plant-bearing series of India,' by Dr. H. F. Blanford, Quart. Journ. Geol. Soc., vol. xxxi. p. 519, in which the whole subject is well discussed.

[3] 'Records of the Geol. Survey of India,' vol. xix. pt. i. 1886.

and with shifting currents. The shales, which form lenticular masses fifteen to twenty feet thick, exhibit impressions of ferns and other plants. Occurring in irregular patches throughout the series are separate angular blocks of the same shale, of all sizes up to twenty feet in diameter, imbedded in the sandstone in the most confused way, some of them standing on end, and others inclined at all angles. Sometimes they are slightly curved as though they had been bent while in a semiplastic condition; and the shale-beds sometimes terminate abruptly, as though broken off. Mr. Wilkinson considers that the shale-beds must have been disturbed by some such agency as that of moving ice[1].

Phenomena similar to those seen in India have been observed by Mr. G. W. Stow at the base of the Karoo beds (the Ecca beds?) of South Africa. In Natal, Dr. Sutherland describes[2] one of these Permian boulder-beds, in which fragments of granite, gneiss, quartzite, clay-slate, etc., varying in size from small pebbles to blocks of five to ten tons, are imbedded in a bluish grey, argillaceous matrix, often showing ripple-marked laminæ. The boulders are smoothed but not rounded; some of them are referred to rocks which occur *in situ* only at a distance of fifty to sixty miles. The older rocks (Devonian? and Silurian) which lie beneath the boulder-beds have their upper surface in many instances deeply grooved and striated, as if the overlying mass had passed over it with force. Dr. Sutherland considered that these beds are of a nature analogous to the Glacial Drift of North-Western Europe. Mr. Griesbach also notices the boulders, often of large size and angular, around Pietermaritzburg. They are so abundant as to form a characteristic feature in the scenery of that part of Africa.

However extraordinary these facts may appear, they are supported by the testimony of so many competent observers that a reasonable *primâ facie* case is established in favour of the possibility of a cold period in Permian times. It is established that these boulder-deposits contain blocks of a large size, which have been transported from a distance, but nevertheless showing little wear, being generally more or less angular,—that occasionally not only are these blocks striated on two or more sides, but also the underlying surface of rocks is smoothed, scored, and striated,—that the blocks are not in the angle of repose incident to current-action, but lie at all angles,—and further that they are imbedded in a matrix of fine laminated and ripple-marked silt, that must have been washed away had they been brought down by the agency of running water.

Now all these are points on which we have been accustomed to rely in support of ice-action in the deposits of the admitted Glacial Period of late Tertiary times; but one other class of evidence which we have

[1] 'Trans. Roy. Soc. of New South Wales,' 1879 or 1880.
[2] 'Quart. Journ. Geol. Soc.,' vol. xxvi. p. 514.

in the latter instance, is wanting in the Permian. In the former both the marine and land Fauna, as well as the Flora, afford indisputable evidence of a special population adapted to a cold climate, whereas in these Permian strata, Carboniferous genera, such as Productus, Conularia, and others, occur, associated with the Labyrinthodonts and Fishes of a later period, and with them is a varied vegetation of Ferns, Conifers, and Cycads. It is true we can only surmise what may have been the habits of the extinct forms; but looking to the fact that in the Triassic Fauna there are the descendants of genera which co-existed with the Palæozoic corals and crinoids, and flourished with the rank Coal-measure vegetation, and that the Permian series itself abounds in cycadaceous plants, of genera which were continued through the succeeding period of the great reptiles, and of families which are still confined to the hotter regions of the Earth,—it is difficult to conceive that such a Fauna and such a Flora could have lived during a period of great cold. That both were greatly depauperised during the Permian period there can however be no doubt.

Another point is that the exact correlation of the Indian, Australian, and South-African beds is not yet well established. It is partly assumed on the very evidence of the boulder-beds themselves. Nor is it clear where the ice-centres could have been. The main elevation of the Himalayas took place in Tertiary times; still it began, though we know not how far it was carried, in Palæozoic times. But the basin of the Godavery is far beyond the range of the Himalayas, and not in the vicinity of existing mountains of any great height. In Australia and South Africa there were important disturbances and mountain-elevation in Palæozoic times, but none apparently of the importance of the great mountain-chains of Europe and America, though the difference in age may to some extent account for this. Another circumstance has to be considered in connection with the general condition of the period. In Central Europe the Permian strata contain enormous stores of salt: if these are the product, as for various reasons appears probable, of the drying-up of lagoons and inland seas, it would seem impossible that a process requiring so much heat, and so prolonged an evaporation, should have taken place in Central Europe, and that, at the same time, ice-work on so large a scale should have been in action around the Indian Ocean area, so near the tropics as latitude 18° to 20° North and 25° to 30° South.

Whether we are to look to the agency of moving ice, in which case the result can scarcely be attributed to any other than an exceptional cosmical cause, or to the agencies of any of the other causes before suggested, it is a problem for the solution of which further inquiry is necessary—an inquiry embracing all the possible contingencies, and not limited by known antecedents.

CHAPTER X.

REVIEW OF THE PALÆOZOIC SERIES.

SPECIAL ORGANISMS. RELATIVE PROPORTION OF GENERA AND SPECIES. CLASSES OF THE ANIMAL KINGDOM IN PALÆOZOIC TIMES. GEOLOGICAL ORDER OF THEIR FIRST APPEARANCE. ORDERS AND GENERA PECULIAR TO THE PALÆOZOIC PERIOD. NUMERICAL TABLE OF SPECIES IN EACH CLASS OF THE ANIMAL AND VEGETABLE KINGDOMS IN PALÆOZOIC TIMES.

Special Organisms. It may be convenient, before passing on to the Mesozoic series, to recapitulate briefly the main palæontological characters of the Palæozoic Period, and to describe the general palæontological features by which the strata of that age can anywhere be recognised. This is readily done, as so large a number of the forms of life whether of the Vegetable or Animal Kingdom are peculiar to this series of rocks, and do not pass beyond them. The *species* which characterise the several divisions have already been mentioned in describing those divisions; and while each Formation has its peculiar species, the *genera* to which they belong have a wider range, some of them extending through several Formations and others through all. Many of them are, however, restricted entirely to the Palæozoic Period; in fact only a limited number of the genera pass up into the Mesozoic. Even the several *orders* and *families* to which these genera belong are, in some cases, restricted to the Palæozoic Period; but their number is limited, and the larger proportion pass up into the Mesozoic and Cænozoic series. By noting these conditions, it is easy in a preliminary inspection to know at once whether one has to deal with Palæozoic or with strata of more recent periods [1].

Relative Proportion of Genera and Species. It is a matter of much interest to note the successive appearance of the different forms of life in this early period. The marine Invertebrata, which are the first to appear, preponderate largely throughout; and it is only later in the series that marine Vertebrata appear, and they are then confined to a few groups and hold only a subordinate position. Certain forms of life have now been traced down nearly to the base of the Cambrian

[1] The especial Palæozoic Crustacea, Brachiopoda, and Mollusca are figured in Plates I to V.

series. Few in number in the lower division of the Cambrian, there are nevertheless representatives of seven out of the ten great divisions of the Animal Kingdom; and this commencement, small at first, rapidly expands by multiplication of genera and species. It is interesting to note in the earlier periods how specialised the genera are; and how the number of species belonging to the several genera gradually increases with the course of time. In the Tremadoc, the Cephalopods are represented by two genera each with one species; in the Llandeilo beds by three genera and seven species; and, while in the Caradoc there are eight genera with forty-seven species, in the Wenlock there are five with thirty; in the Middle Devonian four with thirty-three; and in the Carboniferous nine with one hundred and fifty-four species. Or, taking the several larger divisions, the proportion of genera to species in the Mollusca in the ascending Geological series increases in the following approximate ratio:—

Carboniferous	1 Genus	:	17 Species.
Devonian	1 ,,	:	10 ,,
Upper Silurian	1 ,,	:	7 ,,
Lower Silurian	1 ,,	:	6 ,,
Cambrian	1 ,,	:	1 ,,

Looking at the variety of forms found in the lowest of the Cambrian series, there is reason to suppose that earlier forms must have existed in pre-Cambrian times, for we have in the conglomerates at the base of the Longmynd rocks, clear evidence of older rocks and of older lands, although the latter in Britain are so highly metamorphosed (and so many are of igneous origin) that the absence of organic remains is easily accounted for. There is, however, some proof in the Canadian Eozoon that low forms of life did exist in Archæan times; and the presence of seams and beds of Graphite in the same rocks gives probability to the existence of an abundant vegetable life, although it was probably limited to marine plants alone.

The remnants of the older lands, which have been described in a former chapter, may be but the mountain-tops or high plateaux of an extended pre-Cambrian continent, stretching from Northern Europe to Siberia, and forming large tracts in Northern America. We have reason at present to suppose that, although the seas were peopled, these old primeval lands were barren and destitute of all life, for not a trace of a land plant or of land life of any form is met with until we reach the Silurian series.

Classes of Life in Palæozoic Times. The seas, which were at first sparsely inhabited, gradually teemed with life, of which the character and order of succession throughout the Palæozoic Period are now tolerably well ascertained, although it must be remembered that the negative evidence is always liable to be disproved by the evidence of facts. The summary of the Life of the Palæozoic Period, and the order of appearance of the different classes, shows that of—

Mammals	There are none.
Birds	None.
Reptiles	Protorosaurus in the Permian.
Amphibians	Confined to the order of Labyrinthodonts (which make their first appearance in Carboniferous strata) and Salamandroid Amphibians.
Fishes	Placo-ganoid and Elasmobranch Fishes first appear in the Upper Silurian. There are no Teleostean or bony Fishes.
Molluscs	All the classes are represented: Cephalopods first appear in Upper Cambrian. Pteropods first appear in Lower Cambrian. Heteropods first appear in Upper Cambrian. Gasteropods first appear in Lower Silurian. Lamellibranchs first appear in Upper Cambrian.
Molluscoids	Brachiopods first appear in Lower Cambrian. Polyzoa first appear in Lower Cambrian.
Insects	Belonging to the orders of Coleoptera, Orthoptera, and Neuroptera first appear in Carboniferous strata (*in Devonian in North America*).
Myriapods	One order—the Chilognatha—is first represented in the Carboniferous period.
Arachnids	Scorpionidæ and Arachnida appear in the Coal-measures (*the former appears in Silurian in Sweden*).
Crustaceans	Ten out of the thirteen orders are represented: Macrurous Decapoda and Stomapoda first appear (*in America*) in Carboniferous strata. Isopoda first appear in Devonian. Amphipoda first appear in Upper Silurian. Xiphosura first appear in Upper Silurian. Eurypterida first appear in Upper Silurian. Trilobita first appear in Lower Cambrian. Phyllopoda first appear in Upper Cambrian. Ostracoda first appear in Lower Cambrian. Cirripedia first appear in Upper Silurian.
Annelids	First appear in the Lower Cambrian.
Echinoderms	Crinoidea first appear in Upper Cambrian. Ophiuroidea and Asteroidea first appear in Lower Silurian. Echinoidea first appear in Upper Silurian. Cystoidea first appear in the Lower Cambrian, and Blastoidea in the Upper Silurian.
Actinozoans	The orders of Tabulate Sclerodermata and the Rugosa first appear in Lower Silurian. The Aporosa are absent.
Hydrozoans	Commence with the Lower Cambrian.
Spongidæ	Commence with the Lower Cambrian.
Protozoans	Foraminifera with the Laurentian rocks (?). Lower Silurian.
Plants	Of Angiospermous Exogens there are none; marine plants commence with the Lower Cambrian, land plants with Upper Silurian.

Geological Order of first and last appearance. Or, if we take the strata in geological order, the range in time of some of the great orders and families are broadly as under:—

LAURENTIAN.

First appearance of Protozoa (*Eozoon*) and Fucoids (?) (*in America*).
Disappearance of Eozoon.

CAMBRIAN.

Longmynd . . First appearance of Spongidæ, Annelida, Crustacea (*Trilobita, Ostracoda*), Brachiopoda, Pteropoda, and Algæ (?).

Menevian . . First appearance of Echinodermata (*Cystoidea*).

Lingula-flags . First appearance of Hydrozoa, Phyllopoda, and Heteropoda.

Tremadoc . . First appearance of Crinoidea, Asteroidea, Lamellibranchiata, and Cephalopoda.

Disappearance of Paradoxides.

SILURIAN.

Lower . . . First appearance of Graptolitidæ,—of Trilobites of the genera, Trinucleus, Ogygia, Asaphus, Calymene, and Phacops,—of Actinozoa, Polyzoa, and land plants (*Protostigma, North America*).

Disappearance of Diprionidian Graptolites.

Upper . . . First appearance of Crustacea of the order of Eurypterida, Echinoderms of the order of Blastoidea, and Fishes of the order of Placoganoidei.

Disappearance of Monoprionidian Graptolites, Cystoidea, Calymenidæ, Tentaculites, Lituites.

DEVONIAN.

First appearance of Isopoda (*Præarcturus*), of Fishes of the order Lepidoganoidei (*Crossopterygidæ and Acanthodidæ*), and of Gymnospermous plants. (Insects *in North America.*)

Disappearance of Pentremitidea; of Clymenia; of Receptaculites.

CARBONIFEROUS.

First appearance of Fishes of the group Lepidosteidæ (*Palæoniscus, Amblypterus*, and *Platysomus*); of Stomapoda, Arachnida, Myriapoda, Insecta. (Land shells, *Nova Scotia*).

Disappearance of Favositidæ, Blastoidea, Trilobita, Eurypteridæ, Beyrichia, Leperditia, Bellerophon, Sigillaria, Caulopteris.

PERMIAN.

First appearance of Lacertilia (*Protorosaurus*); of Amphipoda (*Prosoponiscus*); of the Conifers of the genera Ullmania and Walchia.

Disappearance of Platysomidæ, Productus, Lepidodendron, Calamites (?), Noeggerathia, Annularia.

Orders and Genera peculiar to the Palæozoic Period. The following are some of the more common extinct genera (for their place in nature see Chapter V, Vol. I.) that are confined exclusively to the Palæozoic Period, with the exception of the few marked with an asterisk, which reappear for a time in the Hallstatt Trias.

PLANTS.

Cryptogams . Odontopteris, Neuropteris, Sigillaria (*Stigmaria*), Lepidodendron, Ulodendron, Calamites.

Gymnosperms (Conifers). Dadoxylon, Pinites.

PROTOZOA.

Foraminifera . Fusulina, Archædiscus, Nodosinella.

Spongida . . Protospongia, Receptaculites, Ischadites.

Hydrozoa . . The entire order of Graptolites; Dictyonema.

Actinozoa . . Favosites, Omphyma, Heliolites, Halysites, Lithodendron, Petraia, Cyathophyllum, Acervularia.

ECHINODERMATA.

Echinoidea . Palæchinus, Eocidaris, Melonites.

Crinoidea . . Cyathocrinus, Platycrinus, Taxocrinus, Haplocrinus, Poteriocrinus, Eucalyptocrinus, Glyptocrinus.

Cystoidea . . Echinosphærites, Glyptosphærites, Apiocystites.

Blastoidea . .	Pentremitidea, Pentremites, Mesoblastus.
Asteroidea . .	Palæaster, Protaster, Palæocoma, Palæasterina, Lepidaster.
	VERMES.
Annelids . .	Nereites, Cornulites.
	ARTHROPODA.
Crustacea . .	All the genera of the orders Trilobita and Eurypterida; Leperditia, Beyrichia, and Kirkbya amongst the Ostracoda; and Dithyrocaris and Ceratiocaris amongst the Phyllopoda.
	MOLLUSCOIDEA.
Polyzoa. . .	Fenestella, Discopora, Ptylodictya.
Brachiopoda .	Atrypa, Athyris, Chonetes, Camarophoria, Leptæna, Lingulella, Merista, Obolella, Orthis, Pentamerus, Productus *, Spirifer, Strophomena, Stringocephalus, Cyrtina, Retzia, Uncites, Stricklandinia, Meristella.
	MOLLUSCA.
Lamellibranchiata.	Aviculopecten, Cardiola, Modiolopsis, Pterinea, Ctenodonta, Grammysia, Orthonota, Megalodon, Anthracosia.
Gasteropoda .	Euomphalus, Murchisonia *, Holopella, Loxonema, Macrocheilus *.
Pteropoda . .	Conularia, Theca, Tentaculites.
Heteropoda .	Bellerophon *, Porcellia, Maclurea.
Cephalopoda .	Actinoceras, Orthoceras *, Phragmoceras, Asc ceras, Lituites, Clymenia, Goniatites.
	FISHES.
Placoganoids and Lepidoganoids.	Holoptychius, Osteolepis, Palæoniscus, Gyracanthus, Onchus, Cephalaspis, Coccosteus, Pterichthys, Megalichthys. (*All the fishes of this period belong to the class of 'Palæichthyes' of Günther.*)
	AMPHIBIANS.
Labyrinthodonts.	Archegosaurus (*Germany*), Anthracosaurus, Loxomma, Keraterpeton, Brachyops (*India*), Pholidogastes, Lepterpeton, Baphetes and Dendrerpeton (*Nova Scotia*), and the many French and Bohemian forms.

Some of the principal and most typical genera of this primæval life, belonging to the *Trilobita* and the *Brachiopoda*, together with a few characteristic *Mollusca* peculiar to Palæozoic times, are figured in Plates I to V. The other forms of life which, though equally typical of Palæozoic times, are more restricted in their range, such as the *Graptolitidæ*, *Cystoidea*, *Blastoidea*, &c., are figured in the several divisions which they more particularly characterise. The numerical distribution of the forms of life throughout Palæozoic times is given in the following Table, which is compiled chiefly from Mr. Etheridge's Anniversary Addresses to the Geological Society in 1881 and 1882, supplemented by the additional tables given by him in the recent edition of Phillips's 'Geology,' to which and to the volume by Professor Seeley the student should refer for more special and fuller palæontological details [1].

[1] The student will find in Mr. W. H. Baily's 'Figures of characteristic British Fossils, with Descriptive Remarks,' vol. i, a very useful guide to the peculiar and characteristic fossils of the several divisions of the Palæozoic series.

TABLE VII.—SHOWING THE CHARACTER AND THE DISTRIBUTION OF THE SPECIES OF ORGANIC REMAINS IN THE SEVERAL MAIN GROUPS OF THE PALÆOZOIC SERIES IN THE BRITISH AREA.

				Silurian.							Cambrian.			
				Upper.			Lower.				Upper.		Lower.	
	Permian.	Carboniferous.	Devonian.	Ludlow.	Wenlock.	May Hill.	Llandovery.	Bala or Caradoc.	Llandeilo.	Arenig.	Tremadoc.	Lingula Flags.	Menevian.	Longmynd.
1. Mammals... ...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
2. Birds	...	...	...	...	...	...	...	...	...	...	...	...	...	...
3. Reptiles (Lacertilian)	2	...	...	...	...	...	...	...	...	...	...	...	...	...
4. Amphibians, including foot-prints	15	26	...	...	...	...	...	...	...	...	...	...	...	...
5. Fishes	23	5	120	15	...	...	...	...	...	...	...	...	...	...
6. Cephalopods ...	1	154	60	37	30	19	8	47	7	4	2	...	...	...
7. Pteropods... ...	1	1	1	3	3	1	1	10	3	8	12	2	6	2
8. Heteropods ...	...	29	8	7	8	11	6	16	7	6	4	1	...	...
9. Gasteropods ...	26	225	45	33	27	28	13	53	12	4	...	...	...	...
10. Lamellibranchs	37	386	63	71	44	29	3	76	6	6	12	...	...	...
11. Brachiopods ...	36	175	114	48	101	65	59	109	34	18	18	13	6	6
12. Polyzoa	6	78	11	3	24	7	5	21	...	...	1	1	...	...
13. Insects	...	3	...	...	...	...	...	...	...	...	...	...	...	...
14. Arachnida and Myriapoda ...	...	8	...	...	...	...	...	...	...	...	...	...	...	...
15. Crustaceans ...	29	173[1]	36	97	78	24	25	146	45	48	39	51	32	13
16. Worms (Annelids)	3	34	2	17	35	4	3	16	9	11	...	5	3	5
17. Echinoderms ...	2	139	28	21	68	5	2	32	4	...	3	...	1	...
18. Hydrozoa ...	...	3	...	8	30	33	50	38	44	42	2	...	...	2?
19. Corals	5	144	55	17	76	32	26	40	3	...	...	...	...	...
20. Sponges	5	14	7	10	5	2	3	10	1	...	...	1	4	3
21. Foraminifera ...	12	43	...	...	...	...	3?	...	...	...	...	...	...	...
22. Land Plants[2] ...	26	328	27	5	...	1?	...	...	...	...	...	...	...	...
Total ...	229	2316	577	392	529	261	207	614	175	147	93	74	52	31

[1] Of these, 137 are Entomostraca.

[2] Marine plants are supposed to extend to the base of the Cambrian, but some uncertainty attaches to many of these owing to the difficulty, at times, of distinguishing them from Annelid and other trails and markings.

PLATE I.

PALÆOZOIC CRUSTACEA.

Trilobites.

Cambrian.

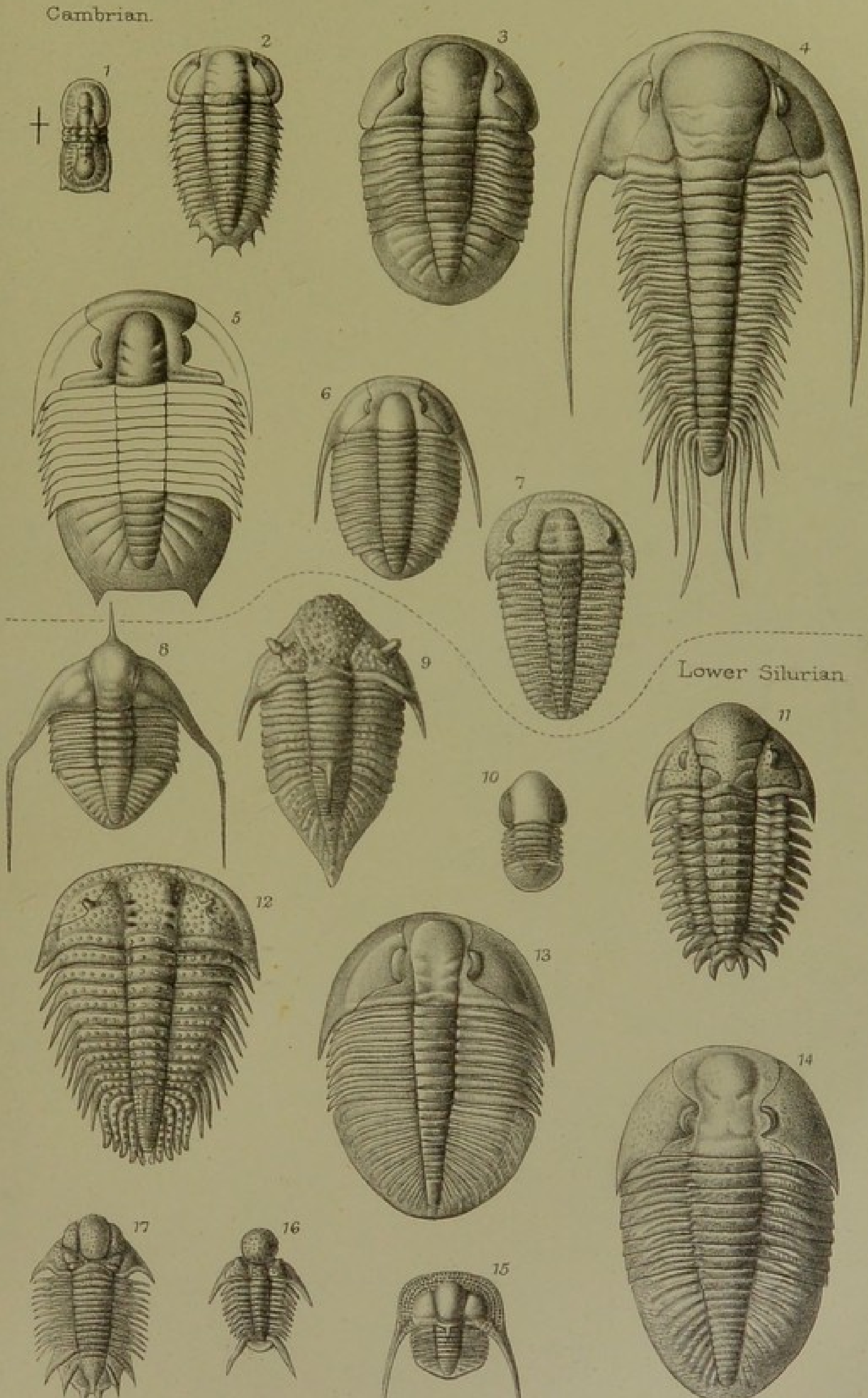
1.	Agnostus princeps, *Salt.*	*Lingula-Flags.*
2.	Olenus scarabæoides, *Wahl.*	*Lingula-Flags.*
3.	Niobe Homfrayi, *Salt.*	*Tremadoc.*
4.	Paradoxides Hicksii, *Salt.*	*Lingula-Flags.*
5.	Dikelocephalus furca, *Salt.*	*Tremadoc.*
6.	Angelina Sedgwickii, *Salt.*	*Tremadoc.*
7.	Sao hirsuta, *Barr.*	*'Primordial' of Bohemia.*

Lower Silurian.

8.	Ampyx nudus, *Murch.*	*Llandeilo.*
9.	Encrinurus punctatus, *Brünn.* ...	*Caradoc to Wenlock.*
10.	Æglina binodosa, *Salt.*	*Llandeilo.*
11.	Cheirurus bimucronatus, *Murch.* ...	*Caradoc to Wenlock.*
12.	Cybele verrucosa, *Dalm.*	*Llandeilo and Caradoc.*
13.	Ogygia Buchii, *Brongn.*	*Llandeilo.*
14.	Asaphus tyrannus, *Murch.*	"
15.	Trinucleus concentricus, *Eaton.* ...	*Llandeilo and Caradoc.*
16.	Staurocephalus globiceps, *Portl.* ...	*Caradoc to Llandovery.*
17.	Lichas palmatus, *Barr.*	(*Bohemia.*)

Plate I.

PALÆOZOIC CRUSTACEA: TRILOBITES.



G. M. Woodward del. et lith.

Prestwich's Geology, II.— Clarendon Press.

PLATE II.

PALÆOZOIC CRUSTACEA.

TRILOBITES.

Upper Silurian.

1.	Calymene Blumenbachii, *Brongn.* ...	*Caradoc to Ludlow.*
2.	Illænus (*Bumastus*) Barriensis, *Murch.*	*Wenlock.*
3.	Acidaspis mira, *Beyr.*	*Caradoc to Wenlock.*
4.	Cyphaspis megalops, *M^cCoy.*	*Caradoc to Ludlow.*
5.	Phacops caudatus, *Brongn.*	*Llandovery to Ludlow.*
6.	Proëtus Stokesii, *Murch.*	*Wenlock.*
7.	Homalonotus delphinocephalus, *Green.*	*Wenlock to Ludlow.*

Devonian.

8.	Phacops latifrons, *Brongn.*	*Lower to Upper Devonian.*
9.	Proëtus Cuvieri, *Stein.*	*Middle Devonian* (*France*).
10.	Phacops (Trimerocephalus) lævis, *Münstr.*	*Upper Devonian.*
11.	Bronteus flabellifer, *Goldf.*	*Lower, Middle and Upper Devonian.*
12.	Harpes macrocephalus, *Goldf.*	*Middle and Upper Devonian.*

Carboniferous.

13.	Griffithides globiceps, *Portl.*	*Carboniferous Limestone.*
14.	Brachymetopus Ouralicus, *Portl.* ...	*Carboniferous Limestone.*
15.	Phillipsia Derbiensis, *Martin.*	*Carboniferous Limestone.*

PLATE II.

PALÆOZOIC CRUSTACEA: TRILOBITES.

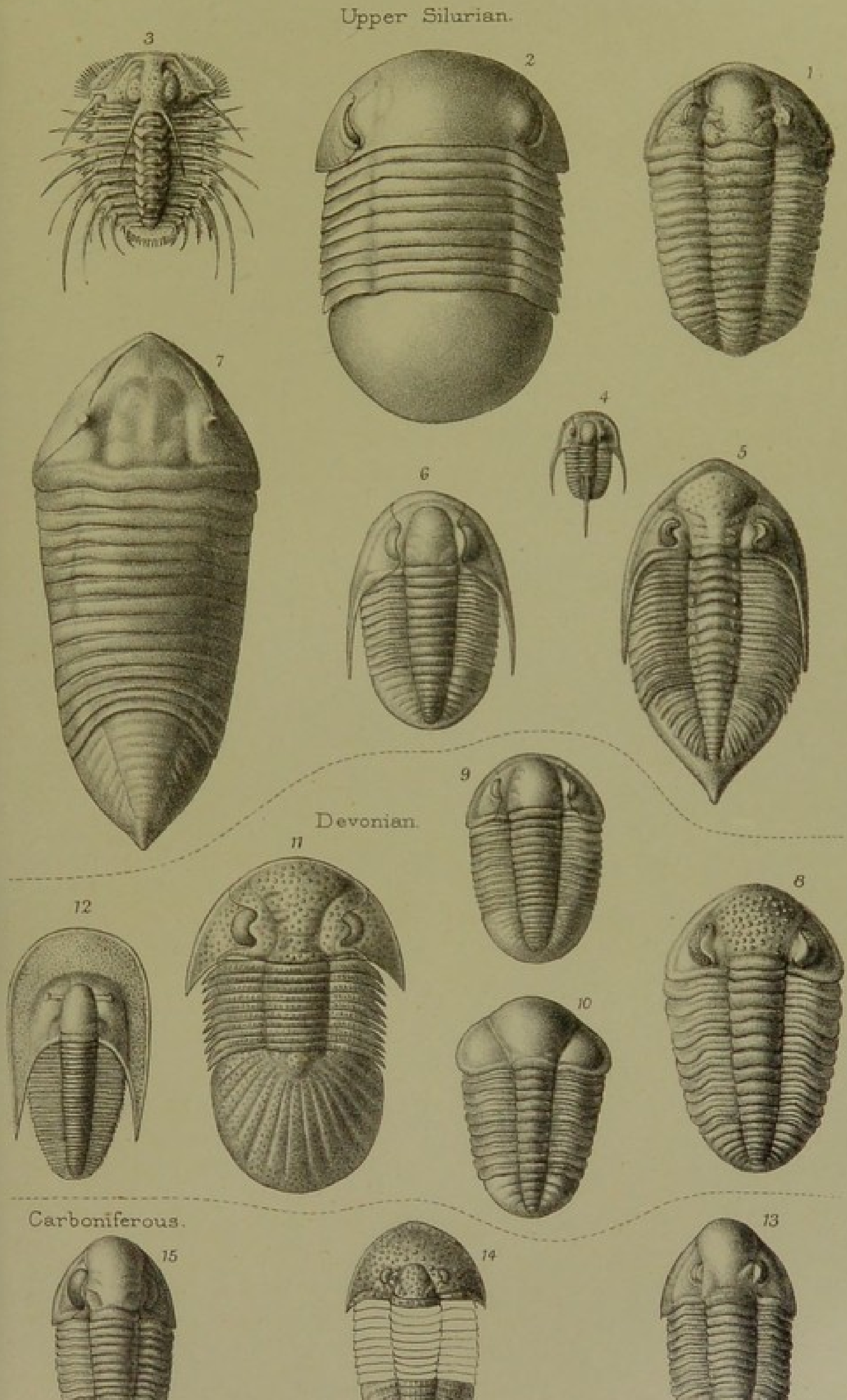


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PLATE III.

PALÆOZOIC BRACHIOPODA.

Cambrian.

1.	Obolella sagittalis, *Salt.*	... ...	*Lingula-Flags.*
2.	Lingulella ferruginea, *Salt.*	... ...	*Longmynd to Lingula-Flags.*
3.	Orthis lenticularis, *Dalm.*	... ...	*Upper Lingula-Flags and Tremadoc.*

Silurian.

4.	Stricklandinia lens, *Sby.* ...	... ...	*Llandovery and May Hill.*
5.	Leptæna transversalis, *Wahl.*	... ...	*Caradoc to Wenlock.*
6.	Atrypa reticularis, *Linn.*	... ...	*Llandovery to Upper Devonian.*
7.	Strophomena rhomboidalis, *Wilck.*	...	*Caradoc to Ludlow.*
8.	Orthis biforata, *Schloth.* ...	... ...	*Caradoc (?) to Wenlock.*
9.	Orthis alternata, *Sby.* ...	... ...	*Caradoc.*
10.	Spirifer plicatellus, *Linn.*	... ...	*Wenlock and Ludlow.*
11.	Meristella tumida, *Dalm.*	... ...	*Wenlock and Ludlow.*
12.	Pentamerus oblongus, *Sby.*	... ...	*May Hill and Llandovery.*
13.	Siphonotreta micula, *McCoy.*	... ...	*Llandeilo.*
14.	Strophomena grandis, *Sby.*	... ...	*Caradoc.*

Plate III.

PALÆOZOIC BRACHIOPODS.

Cambrian.

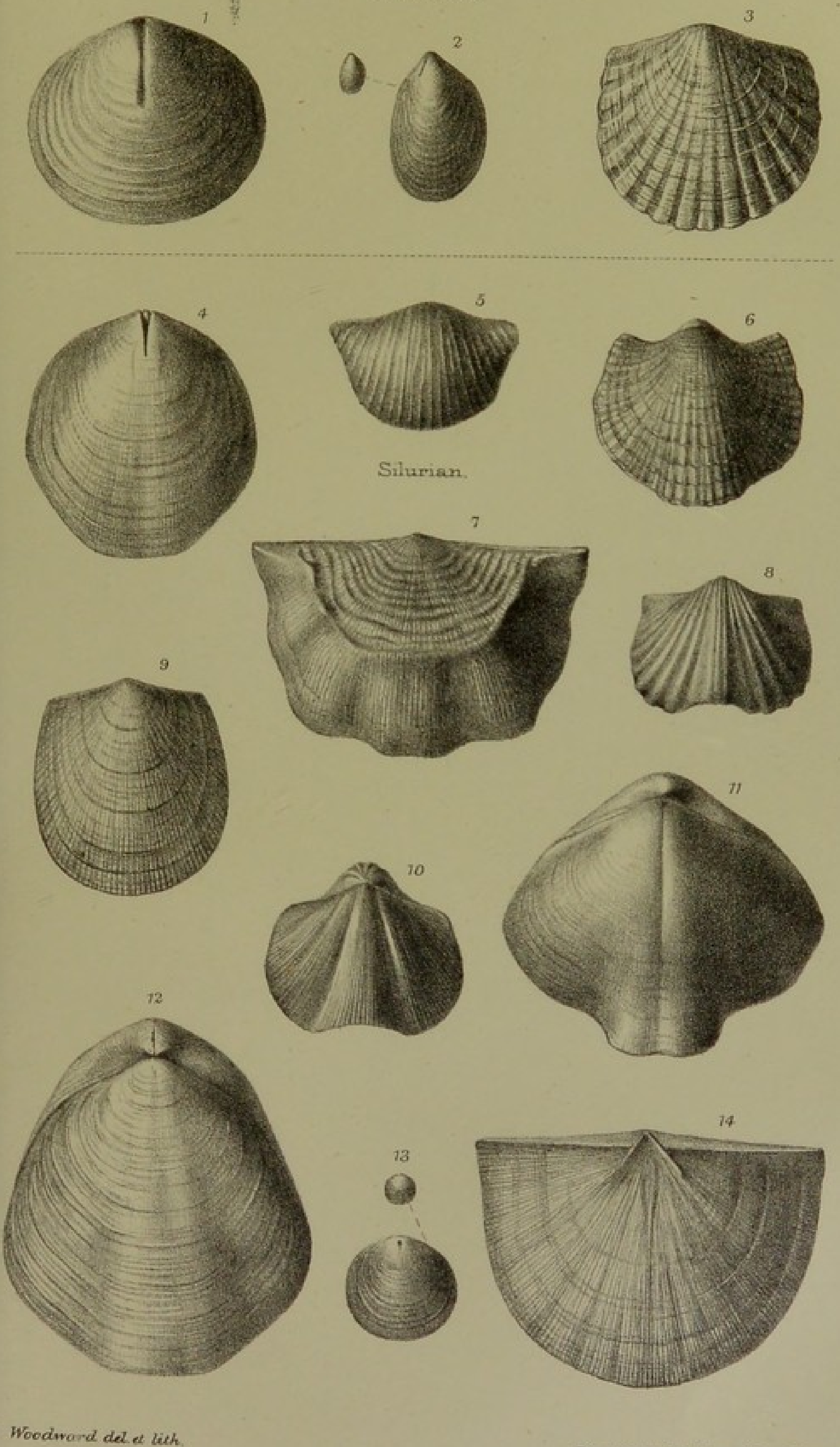

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PLATE IV.

PALÆOZOIC BRACHIOPODA.

Devonian.

1.	Stringocephalus Burtini, *Defran.* ...	*Middle Devonian.*
2.	Retzia ferita, *Von Buch.*	*Middle Devonian.*
3.	Uncites gryphus, *Schloth.*	*Middle Devonian.*
4.	Merista plebeia, *Sby.*	*Middle Devonian.*
5.	Chonetes Hardrensis, *Phill.*	*Upper Devonian and Carboniferous.*
6[1].	Orthis interlineata, *Sby.*	*Middle and Upper Devonian.*
7[1].	Cyrtina heteroclita, *Defran.*	*Middle Devonian.*
8[1].	Spirifer disjunctus, *Sby.*	*Middle and Upper Devonian.*

Carboniferous.

9.	Productus semireticulatus, *Martin.* ...	*Carboniferous Limestone and Coal-Measures.*
10.	Retzia radialis, *Phill.*	*Carboniferous Limestone.*
11.	Athyris Roysii, *Léveillé.*	*Carboniferous Limestone.*
12.	Spirifer striatus, *Martin.*	*Carboniferous Limestone.*

Permian.

13.	Spirifer alatus, *Schloth.*	*Magnesian Limestone.*
14.	Camarophoria Schlotheimi, *Von Buch.* ...	*Magnesian Limestone.*
15.	Productus horridus, *Sby.*	*Magnesian Limestone.*

[1] The separating line in the Plate should run below instead of above these three species.

Plate IV.

PALÆOZOIC BRACHIOPODS.

Devonian.

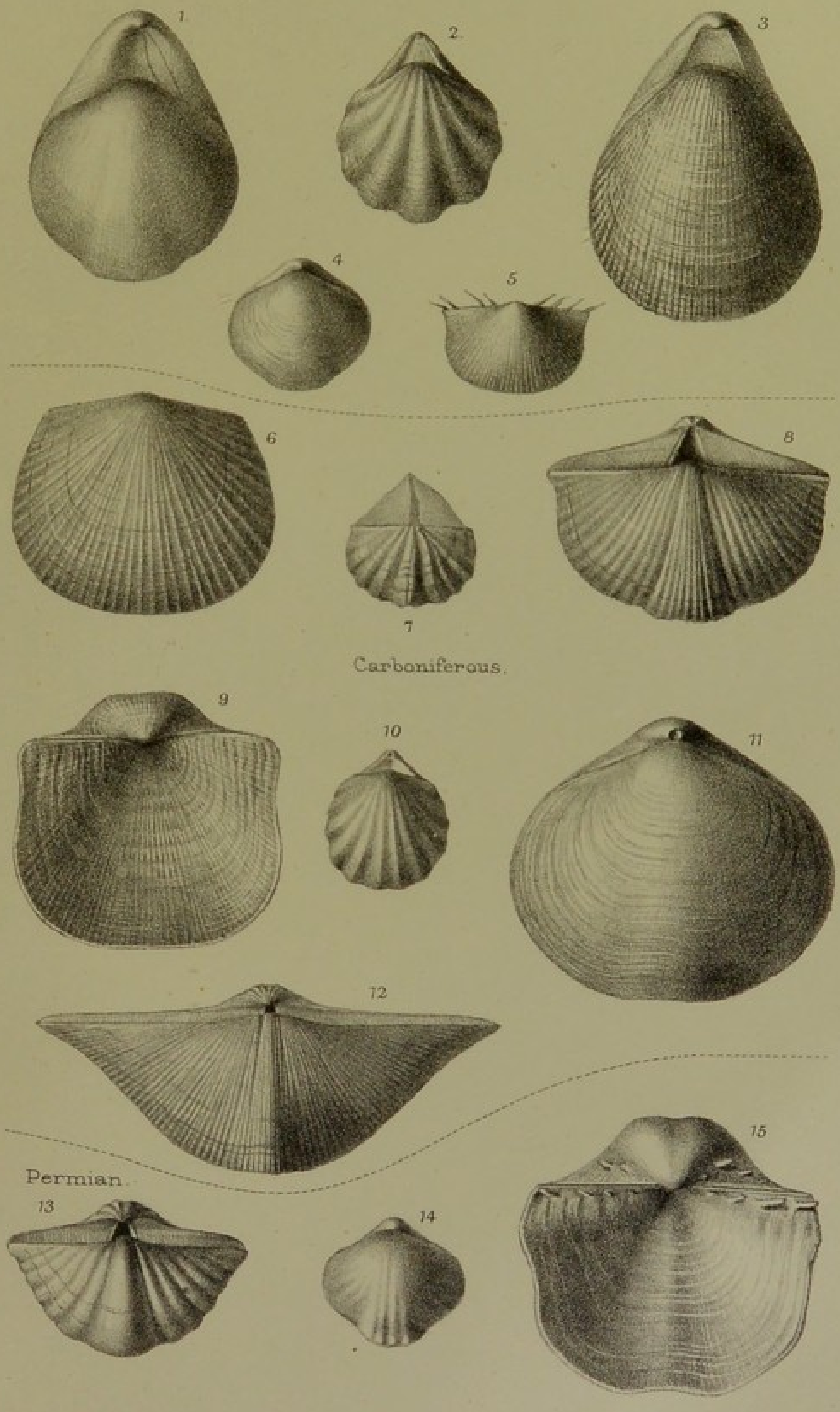

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PLATE V.

PALÆOZOIC MOLLUSCA.

Silurian.

1.	Pterinea Danbyi, var. ampliata, *Phill.* ...	*Upper Silurian.*
2.	Grammysia cingulata, *Hiss.*	*Wenlock and Ludlow.*
3.	Bellerophon expansus, *Sby.*	*Ludlow.*
4.	Acroculia haliotis, *Sby.*	*May Hill and Wenlock.*
5.	Maclurea Peachii, *Salt.*	*Llandeilo.*
6.	Phragmoceras pyriforme, *Sby.*	*Wenlock (?) and Ludlow.*
7.	Orthoceras annulatum, *Sby.*	*Caradoc to Ludlow.*

Devonian.

8.	Macrocheilus arculatus, *Phill.*	*Middle Devonian.*
9.	Megalodon cucullatus, *Sby.*	*Middle and Upper Devonian.*
10.	Murchisonia spinosa, *Phil.*	*Middle and Upper Devonian.*
11.	Goniatites globosus, *Münst.*	*Middle and Upper Devonian.*

Carboniferous.

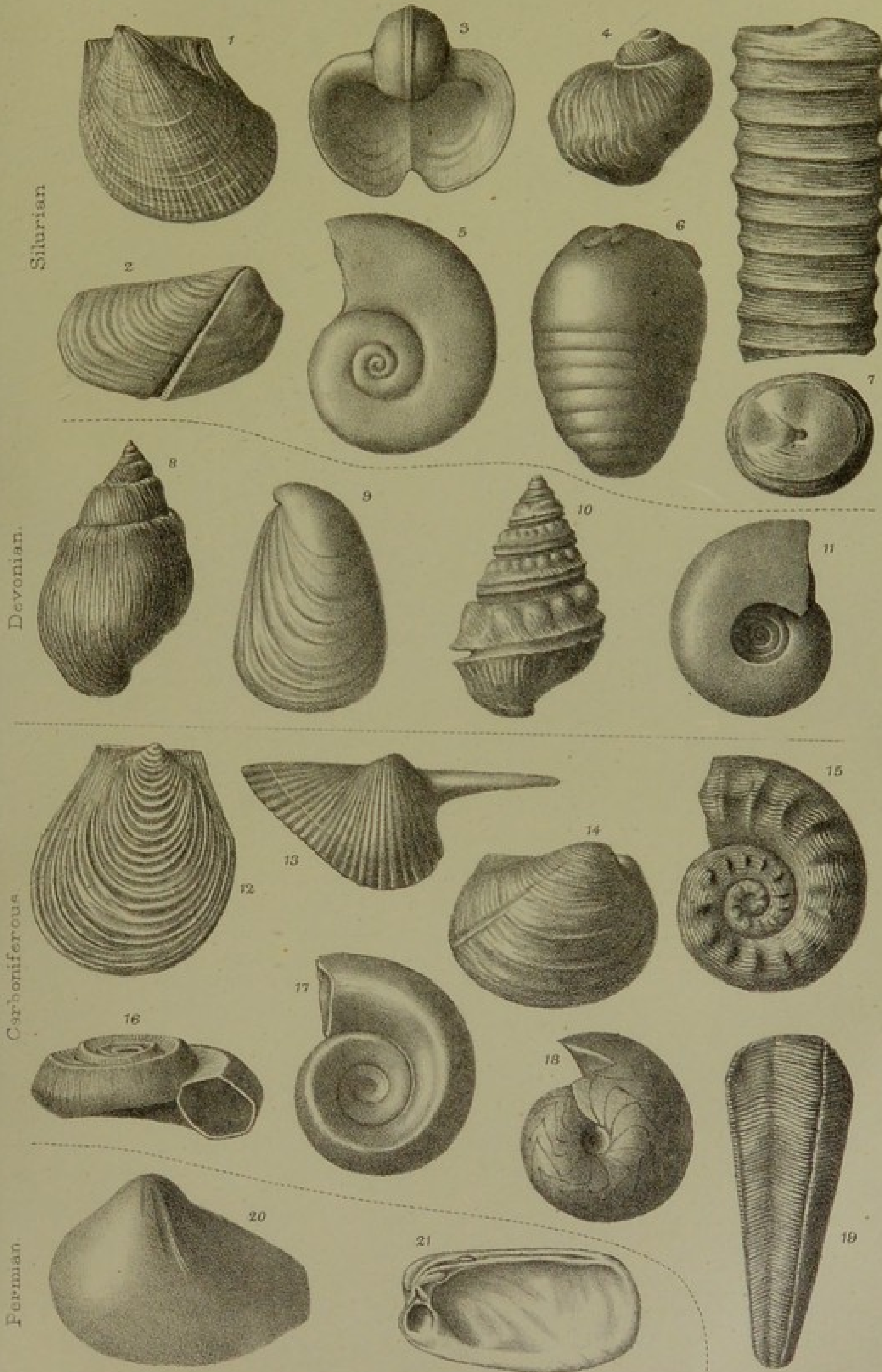
12.	Posidonomya Becheri, *Bronn.*	*Carboniferous Limestone and Coal-Measures.*
13.	Conocardium minax, *Phill.*	*Carboniferous Limestone.*
14.	Edmondia rudis, *M^cCoy.*	*Carboniferous Limestone.*
15.	Porcellia puzio, *Léveil.*	*Carboniferous Limestone.*
16.	Euomphalus pentangulatus, *Sby.* ...	*Carboniferous Limestone.*
17.	Nautilus cariniferus (*Nautiloceras*), *Sby.*	*Carboniferous Limestone and Coal-Measures.*
18.	Goniatites sphæricus, *Martin.*	*Carboniferous Limestone.*
19.	Conularia quadrisulcata, *Sby.*	*Carboniferous Limestone and Coal-Measures.*

Permian.

20.	Schizodus obscurus, *Sby.*	*Magnesian Limestone.*
21.	Pleurophorus costatus, *Brown.*	*Magnesian Limestone.*

Plate V.

PALÆOZOIC MOLLUSCA.



G. M. Woodward del. et lith.

CHAPTER XI.

THE NEW RED SANDSTONE, OR TRIAS.

Triple Division. Muschelkalk wanting. Palæontological and Physical Break. Great Geographical changes. Effects of the Disturbances on the Fauna and Flora. Migrations. Appearance of New Types. The Bunter Sandstone. The Muschelkalk: its Organic Remains. The Keuper Marls and Conglomerates. Salt-Beds. Their Origin. Section of a Boring. Organic Remains. Labyrinthodont Amphibia. Reptiles. Fishes. Rhizopods. Estheriæ. Origin of the prevailing Red Colour of the Trias. Cause of rarity of Fossils. The Rhætic Beds. Organic Remains. Earliest Enaliosaurs and Mammals. Landscape-marble. Foreign Equivalents. France. Germany. Halstatt Beds. The Kössen Beds. North America. India. Australia. South Africa.

Triple Division. This, the lowest of the Secondary or Mesozoic Formations, was originally known as the New Red Sandstone, to distinguish it from the Old Red. The term 'Trias' is of German origin, used to signify the tripartite division of the series on the continent. Of these divisions, only two exist in England. The central division or the Muschelkalk is wanting, unless it be represented by the 'Water-stones.' The total thickness of the Triassic Series, to which the Penarth or Rhætic beds have been added, varies from a maximum of about 5000 feet in Lancashire to 1000 feet in Warwickshire and Gloucestershire. The following are its divisions, and their approximate mean thickness in descending order:—

		Feet.
Penarth Beds, and Black Shales	Rhætic	80
Red Marls with rock-salt and gypsum, and Variegated Sandstones (Waterstones): local Dolomitic Conglomerate ...	Keuper	2000
Wanting	*Muschelkalk*	
Red Sandstones, with intercalated conglomerates	Bunter	700

Palæontological and Physical Break. With this formation great palæontological changes were inaugurated. All the species, a considerable number of the genera, and many of the families, which existed during Palæozoic times, now disappear; and new groups and forms make their appearance. This great break in the sequence of life between the Palæozoic and Mesozoic periods is connected with a great physical break in the sequence of the superposed strata, and indicates a vast lapse of time.

Already we had at the commencement of the Permian period evidence of great disturbances, resulting in the emergence of one portion of the Carboniferous sea-bed, and in the elevation, amongst others, of the Pennine chain and some of the mountain-ranges of the south of France and of Corsica.

But a change of yet greater magnitude took place at the close of the Permian period,—the culminating effort, as it were, of the state of tension manifested by the long continuance of those slow and steady movements of oscillation and general subsidence, that were so constant through Carboniferous times. Large continental areas such as those of East Russia and adjacent parts of Siberia were elevated, and high ranges such as those of the Ardennes, Mendips, and others were raised (vol. I. p. 292, and Pl. v). These transformations of the surface were accompanied by excessive lateral pressure of the strata along the lines of disturbance. Thus, for example, the great chain of hills, just referred to, which passes from Westphalia through Belgium and Somerset, to the south of Ireland, was not only uplifted in anticlinal lines, but the strata were twisted, crumpled, and squeezed into innumerable flexures and contortions. In England, the Carboniferous strata on the flanks of the Mendip Hills, which form one portion of the line of elevation, together with the hills of the south of Wales and Ireland, exhibit, but in a lesser degree, the same phenomena of extreme pressure and contortion, accompanied by an extensive denudation of the whole surface.

In consequence of these disturbances the New Red Sandstone rests in very unconformable superposition on the Permian, Carboniferous, or Devonian rocks, passing transgressively over, or abutting discordantly against, the upturned and fractured strata of the various Palæozoic strata, and filling up and levelling some of the inequalities caused by the previous faulting and axial elevations. These newer strata, being thus largely derived from the wreck and wear of the preceding Permian and other Palæozoic rocks, necessarily retain so much of the petrological character of the original rocks that it is often difficult, in the absence of fossils, to distinguish between strata of Permian and of Triassic age.

FIG. 69. Section of the *Lias* (*e*) and *New Red Sandstone* (*f*) resting unconformably on the *Carboniferous Limestone* (*m*) and *Old Red Sandstone* (*o*), near Wapley, Gloucestershire. (Geol. Survey, reduced ½.)

It generally happens also, that, although the want of conformity is very strongly marked along the main axes of elevation, this unconformity diminishes as the strata recede from those areas of disturbance; so that, for example, whereas on the flanks of the Mendips the Palæozoic strata are tilted up at high angles and the unconformity is very conspicuous, at a distance from this central line, where the strata resume their horizontal position, the unconformity is hardly apparent.

Effects of the Disturbance on the Fauna and Flora. It is not difficult to realise how greatly these changes of land and sea must have affected the organic world; for old continents were submerged, old sea-beds raised, and mountain-chains were uplifted; so that both the climate of the land and the depths of the sea, and consequently its pressure and temperature, were all alike affected. Under such circumstances denizens of the sea suffer more than those of the land, because land animals can in most cases readily move from place to place, and in a measure adapt their location to their necessities; but with the majority of the inhabitants of the sea it is different. Some shells are fixed—all Brachiopods are, except in a very young state,—and, with few exceptions, those which do move, change their places with extreme slowness. Many can only live on shores; some can only live in rather deep water; and the great majority live at short distances from the shore in shallow waters. So also, the reef-building corals can only live between low-water-mark and a depth of 100 feet. Sea-weeds, again, are mostly confined to limited zones of depths. Any important change of level is fatal to these various forms of life. Consequently when a subsidence takes place, if it be only to a moderate extent, a certain number of individuals may escape[1]; but if the subsidence be more considerable, then this portion of the marine population is destroyed, as certainly as a land population would be by a subsidence under water. Further, although the free-swimming cephalopods and fishes would not suffer in like degree; still, as the other classes and the plants on which they feed would be destroyed, they would suffer indirectly, and these changes would necessitate their migration to other feeding-grounds. Nor, for the same reasons, would sudden elevation prove less fatal to one portion of the marine life, while it would lead also to the dispersion of another portion.

It is therefore readily conceivable, whenever the movements were more rapid than usual, supposing them to have been in some relative proportion to those of the present time (Vol. I. p. 222), how, after the great disturbances that took place at the end of the Carboniferous period, the Palæozoic marine population of the European area was wasted and thinned; and how it happened that the nearly 2000 species of marine life of the Carboniferous period, in the English area, dwindled down at the Permian period to 203 species.

From the same causes, the changes in the fauna are equally marked between the Permian and Trias, although, owing to previous losses, they are not of equal magnitude. In Europe and America not one of the species (except possibly some low-life Rhizopods) of the Palæozoic times survived to the Mesozoic period:—not only so, but, as before mentioned, many families became extinct. Graptolites had already succumbed at the end of the

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[1] Including some of the Brachiopods attached to sea-weeds and floating timber.

Silurian, and Trilobites at the end of the Carboniferous period; and now, with one curious exception, at a few spots only in Europe (Halstatt, St. Cassian, Esino), most of the other types of Palæozoic life come to an end. Nevertheless, some of the orders and a few of the genera survived the change.

On the other hand, many new types make their first appearance, but they appear slowly, for in the Trias in this country the number of organic remains amounts to only 78 species[1], though they gradually increase and in the Rhætic beds number 125 species. It is another instance of the gradual re-introduction of a fauna, which, in consequence of the changes of land and sea that occurred at the end of the Permian period, had migrated or had survived at a distance (as in some of the passage-beds described by Gümbel), whence their descendants, together with alien types from other areas, found their way, after a long interval, to the Triassic seas, which had replaced those of the Permian period in the old areas.

A great change takes place in the land flora. The gigantic Cryptogams disappear; and Cycads of definite types, and some Ferns of new species and genera, now form the characteristic vegetation; and with these are associated Coniferæ allied to the Cypresses, Cryptomerias, and Sequoias,—families which so largely abound in later ages.

Saurian reptiles, which occur in such profusion during the Mesozoic period as to have obtained for it the designation of the 'Period of Reptiles,' first appear, it is true, in Permian strata (Protorosaurus in England and other genera on the continent and in America); but it is chiefly Amphibians or Saurobatrachians that then prevailed, and it is not until we come to Mesozoic times that true Reptilia are found in greater abundance and of general higher organisation.

The Lower Division of the Trias, or Bunter Sandstone, in the neighbourhood of Liverpool and of Nottingham, and again in the valley of the Severn around Shrewsbury, Bridgenorth, and Worcester, consists essentially of a very variable series of soft red mottled sandstones, with conglomerates and some breccias of the same red colour. Their varied colours gave rise to the German term 'Bunter,' as also to the French term 'Grès bigarré,' while Brongniart applied to the whole series, including the Permian strata, the term Poikilitic, indicative of the same prevailing condition. The sandstones are always quartzose, frequently micaceous, occasionally argillaceous, and often with thin subordinate seams and nodules of clay. Though red is the prevailing colour, green, yellow, and white are common. They are all used as building-stones; and underground they are largely charged with water, of which advantage is taken for many local water-supplies. The conglomerates consist chiefly of pebbles of light-red quartzites, and of white and reddish quartz, with others of vein-stones,

[1] Of these, thirty-five are Foraminifera of the Keuper.

horn-stone, and metamorphic rocks embedded in a red marly or sandy matrix.

In the cliffs of Budleigh-Salterton, the conglomerate forms thick beds, consisting almost entirely of smooth, well-rounded pebbles, mostly of quartzite, many of which contain abundant impressions of shells. They are of Devonian, Silurian, and possibly Carboniferous species, most of which may be referred to English rocks, though there are some species which have as yet only been found in Normandy[1].

The following illustration shows the main divisions of the Trias and the enormous fracturing it underwent in post-Triassic times, whereby the Silurian rocks are brought up nearly to the same level—a faulting of not less than 2000 to 3000 feet.

FIG. 69*. Section of the Trias on the West side of the Staffordshire Coal-field. (Reduced from the Geol. Survey, ½.)

Keuper. { *a. Red Marl.* *Sandstones (Waterstone).*
Bunter. { *c. Mottled Sandstones.* *d. Conglomerates, Sandstones, and Pebble-beds.*
e. Permian Breccias and Conglomerates.
g. Coal-measures.
h. Probable position of Wenlock Shale.

A stratigraphical character, not so frequent in the older rocks, but constantly occurring in more recent strata, is very common in the Trias. This is the arrangement of the laminæ, known under the name of oblique lamination or false bedding, which is due to the constant rearrangement of shifting sand-banks in shallow seas with variable currents (Vol. I. p. 119). Excellent examples of this structure may often be seen in the many sections of the Bunter. This division of the Trias, which has a thickness of about 1700 feet in Lancashire, diminishes to about 100 feet in Gloucestershire, and thins out altogether as it ranges underground to the south-east of England. Fossils in the Bunter are extremely scarce and confined almost entirely to obscure impressions of plants, some Labyrinthodont footprints, and an Estheria (*E. minuta*).

The Muschelkalk. The next division of the Trias, wanting in Great Britain but forming a very conspicuous member of the series on the Continent, is the well-known 'Muschelkalk' (Shell-limestone) of Germany and the 'Calcaire conchylien' of the French geologists. It consists mainly of beds of light-grey or white compact fossiliferous limestones and marls 600 feet thick. It is sometimes dolomitic, and contains subordinate beds

[1] Davidson, 'Quart. Journ. Geol. Soc.,' vol. xxvi. p. 70; and 'Palæont. Monogr.' for 1882 pp. 317–368.

of rock-salt and gypsum. It commences in Luxembourg, and expands as it trends southwards and eastward, being largely developed in the Vosges mountains and in Germany. It is rich in peculiar organic remains. *Ceratites* is a common and characteristic genus. There are several species, which are distinguished by the peculiar denticulated or crenulated lobes of the septa dividing the chambers, whereas with the true Ammonites the sutures are foliaceous or ramified.

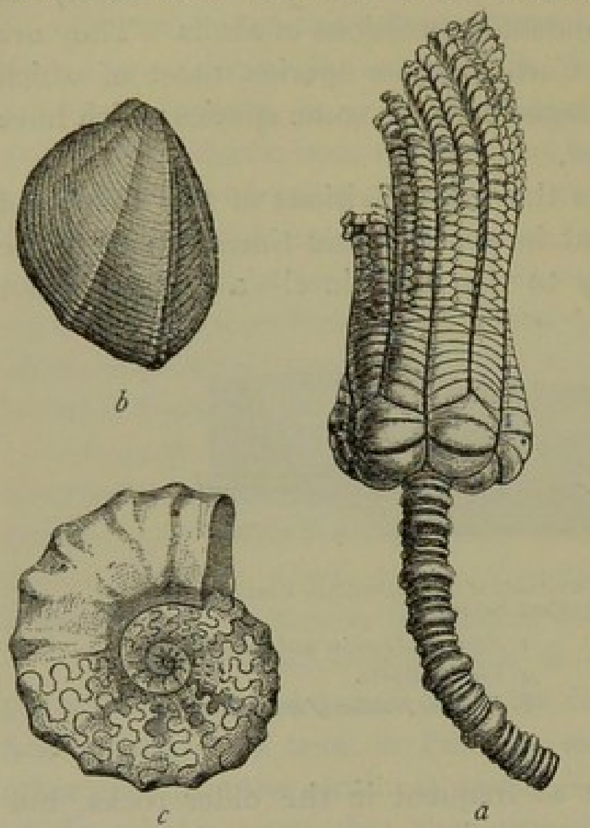

FIG. 70. *a. Encrinus liliiformis*, Schloth.; *b. Myophoria vulgaris*, Bronn; *c. Ceratites nodosus*, de Haan.

Another characteristic fossil of the Muschelkalk is the *Encrinus liliiformis*, or Lily-encrinite, of which the remains are extremely abundant, their stems and plates often constituting entire beds of the limestones. Star-fishes are represented by the *Aspidura loricata*; and the Bivalved Mollusca by large numbers of individuals, but comparatively few species, of which *Gervillia socialis*, *Myophoria* (Trigonia) *vulgaris*, and *M. lineata* are the most characteristic. Crustacea (Macrurous and Entomostracous) are also present, with some Fishes and Reptiles.

Besides Labyrinthodonts, true Reptiles are now more common. Of these are *Simosaurus*, *Nothosaurus*, and *Placodus*, which belong to the order of Sauropterygia. The last genus is distinguished by a character very common amongst the Mesozoic fishes, but very exceptional among reptiles. Instead of the usual pointed teeth of reptiles, it has rounded and obtuse teeth, forming broad plates adapted for crushing crustacea and mollusca. These teeth covered the whole of the upper palate, but the lower jaw had only a single row of teeth. Some of these palatal teeth present crushing surface measuring nearly two inches across.

The Keuper or Upper Division of the Trias. This division consists, in its lower parts, of calcareous and dolomitic conglomerates, with some fissile micaceous sandstones and marls. The conglomerates, where they fringe the northern flanks of the Mendips, are coarse, massive, and without organic remains. The included pebbles are mostly of large size, and with them are boulders of one to two-and-a-half feet in diameter, which, though much worn, are not rounded. They have all been derived from the local Carboniferous Limestone which crops out on the higher ground above the conglomerates. Similar conglomerates, also of local origin, fringe the Malvern and the Abberley hills. In the Bristol area and South Wales this formation is known as the 'dolomitic conglomerate.' This old coast-line, with its pebble-beds, is well shown in the following section:—

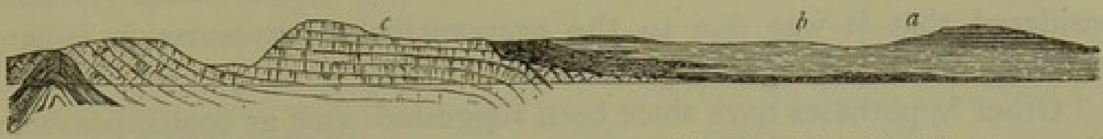

FIG. 71. Section through the Carboniferous Limestone anticlinal five miles N.W. of Bristol. (Reduced from Geol. Survey, sect. ⅙.)

a. Lower Lias. b. New Red Sandstone and Dolomitic Conglomerate. c. Carboniferous Limestone.

The red sandstones and marls that wrap round the old rocks and granites of Charnwood Forest, which, as before mentioned, then rose as an island in the midst of the Triassic sea, are of Keuper age. The vignette at the end of the chapter shows the Keuper here full of fragments and boulders derived from the adjacent old granite cliff.

Next in order to this conglomerate, which is only a local shore-deposit, are the so-called 'Waterstones' (200 to 400 feet thick), which consist of white, yellow, and red sandstones, largely used as building-stones, and important also as water-bearing strata. They are well exhibited in Cheshire, around Kidderminster and Shrewsbury, and in Worcestershire.

To these succeed the Upper Keuper, which consists of a great series of red marls, variegated with grey and green, and with a few subordinate beds of sandstone. This series has a thickness of not less than 3000 feet in Cheshire and Lancashire, but becomes much thinner as it ranges southward. The special mineral features, which give particular interest to this division, are its stores of rock-salt and gypsum.

The salt-beds lie under the New Red Sandstone plains of Cheshire and Worcestershire, and attain their greatest development in the centre of the district, or near the towns of Northwich, Nantwich, and Droitwich, where they are largely worked. The salt forms lenticular beds, from 4 feet to 300 or more thick, more or less pure or else mixed with the red marl, and interstratified with strata of red and variegated marls, and with beds of gypsum (sulphate of lime). The salt is obtained in two ways,—in some districts by sinking shafts and working the solid rock-salt in large galleries, while in other more frequent cases it is obtained by means of brine-springs, which rise to or near the surface on boring through the overlying strata. Generally the first beds passed through are red and greenish clays and sandstones; to these usually succeeds a bed of gypsum, sometimes twenty or thirty feet thick, beneath which salt water is found. This water now often occupies spaces left between the strata, in consequence of the salt having been dissolved out, and these cavities are apt to collapse. The brine-springs are true artesian-wells, the surface-waters taking up the salt as they pass through the saliferous strata which crop out on the higher ground at a distance, as in ordinary artesian-wells (Vol. I. p. 161).

The brine-water contains about 2½ lbs. of salt to the gallon, or about eight times as much as sea-water. With respect to the origin of this salt, one of the best and earliest writers on the subject, Sir Henry Holland[1], considered that it was due to the evaporation of sea-water in isolated sea-basins of Triassic age.

Other hypotheses have since been suggested, such as contemporaneous saline springs and volcanic agency; but our Palæozoic rocks contain no deposits whence such springs could have derived their salt; and the salt in volcanic eruptions is never present in large quantities, being derived from the sea-water which gains access to the volcano towards the close of an eruption.

Geologists now, therefore, generally revert to the older hypothesis, namely, deposition by evaporation from sea-water. This probably took place by the isolation of some portions of the sea-bed and the formation of inland lakes or vast lagoons, which, not being fed by rivers in quantity sufficient to maintain the supply of water lost by evaporation, gradually became so super-saturated with salt as to lead to its deposition in the same way as is now effected artificially in salterns on the sea-coast.

Sea-water contains about 35 parts of solid matter in every 1,000 parts of water; and in 100 parts of this residuum there are 77 to 78 parts of chloride of sodium or common salt, with 22 to 23 parts of other chlorides and earthy sulphates; whereas rock-salt consists of 97 to 98 parts of chloride of sodium with only 2 to 3 parts of the other salts.

There is thus a considerable difference between the saline ingredients of sea-water and rock-salt, inasmuch as in the former there are 10 to 12 per cent. of sulphates, whereas the latter contains generally less than one-half per cent.; they differ also especially in the smaller proportion or absence of the salts of magnesia and potash in the rock-salt[2].

This difference is easily explained by the circumstance that the salts which exist in sea-water possess various degrees of solubility, so that when sea-water is slowly evaporated in salterns, there is first a deposit of the more insoluble sulphate of lime; the saline solution is then removed to other pans, where, after further evaporation, the chloride of sodium is precipitated, while the more soluble salts of magnesia and potash remain in the mother liquor, which is poured off before their point of saturation is reached. The common sea-salt of salterns consists therefore, like

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[1] 'Trans. Geol. Soc.,' vol. i. p. 38. Also a paper by G. W. Ormerod, 'Quart. Journ. Geol. Soc.,' vol. xi. p. 262.

[2] The bromide and chloride of potassium, the chloride of calcium, and carbonate of lime, have been detected in other salt beds of Triassic age, especially in those of the Jura.

rock-salt, essentially of chloride of sodium, with only small proportions of salts of magnesia and lime.

The relation which the salt obtained in salterns on the Hampshire coast and the rock-salt of Cheshire bear to the salts of the sea, and of the Ocean in general, is shown in the following table :—

	Sea-water. The Channel.	Salterns. Lymington.	Rock-Salt. Cheshire.
Chloride of Sodium	77·98	98·80	98·32
" Potassium ...	0·97	...	...
" Calcium	1·39	...	0·21
" Magnesium ...	8·12	0·50	0·18
Bromide of Magnesium ...	0·47	...	...
Sulphate of Lime	3·47	0·20	0·62
" Magnesia ...	6·79	0·50	...
Carbonate of Lime	0·56	...	...
Silicate of Soda	0·25	...	loss 0·67
	100·00	100·00	100·00

What then has become of the excess of sulphate of lime present in the old sea-waters? It has been precipitated and has gone to form, like the salt, lenticular masses of various thickness in the Trias or Permian, or it is irregularly dispersed in the beds of marls. The two minerals are always in association. The following is the section of a boring 391 feet deep, sunk in the Keuper of eastern France, in which six beds of salt alternating with gypsum were traversed :—

SALT-WORKS OF GOUHENANS, HAUTE-SAÔNE.

	Thickness in mètres.
Vegetable soil and red marl	2·00
Blue, red, and grey marls, with a little gypsum	27·18
Gypsum	5·24
Gypsiferous marls	5·06
Gypsum coloured red and blue, and red marl	9·71
Grey marl and gypsum	4·10
Rock-salt	5·64
Saliferous marl	3·90
Red and grey marls, mixed with gypsum	5·58
Red marl mixed with *rock-salt*	7·14
Grey marl, in part mixed with gypsum	3·15
Two beds of rock-salt, divided by a bed of marl	18·28
Very hard gypsum	0·67
Saliferous marl	1·95
Grey marls, mixed with gypsum	4·98
Rock-salt	1·30
Rock-salt between saliferous marls	2·36
Saliferous marl, mixed with gypsum	0·71
Rock-salt	1·17
Gypsiferous marls	3·89
Very hard gypsum	1·37
Grey marl, with white gypsum	1·86
	117·14

In Lorraine, 13 beds of rock-salt, alternating with beds of gypsum, anhydrite, and variegated marls, were passed through in a shaft 706 feet deep.

Alabaster is a white and amorphous form of gypsum. It is translucent, and occurs in massive beds in the Trias of Derbyshire, where it is largely worked as an ornamental soft stone. Sulphate of strontian and fuller's-earth are also found in places in the Keuper marls.

From the constant association of rock-salt and gypsum there is reason to suppose that, as the old salt lakes dried up, there was first precipitation of the sulphate of lime, which went to form beds of gypsum or alabaster; this was succeeded as saturation increased by the precipitation of the salt; further, as the beds of salt alternate with beds of gypsum, we may suppose that there were from time to time subsidences, by means of which fresh supplies of sea-water were let into the lake-basins, so that the process of evaporation and precipitation was from time to time repeated.

In confirmation of the general shallow-water conditions and continued slow subsidence, during great part of the Triassic period, various confirmatory facts may be noticed. One of these is the not unfrequent occurrence of small cubes, more or less perfect, of fine sandstone standing out on the under side of the planes of bedding, and having exactly the form in which salt crystallises; thus indicating that on the shores of the old salt-lakes, crystals of salt were formed by evaporation, as the waters gradually dried up. Subsequently, muddy waters again covered the surface, and, as they slowly dissolved the salt crystals, they filled the hollows thus left with fine silt, which in its turn was consolidated, and thus formed these casts, which represent the original crystals.

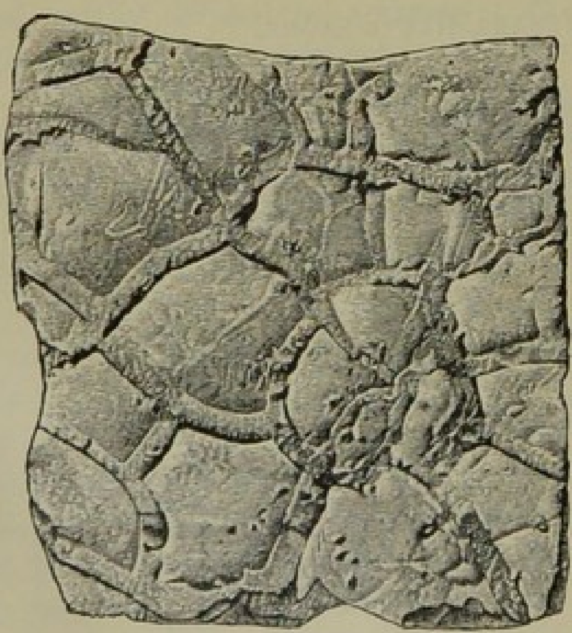

FIG. 72. *Sun-cracks and Tracks of Rhynchosaurus. Trias, Weston, Cheshire.* (From photograph of a block, 3′×3′, in the Oxford Museum).

Another fact corroborative of shallow-water conditions, is the common occurrence of ripple-marked surfaces on the planes of bedding, not unfrequently accompanied with the impression of rain-drops, and sometimes of the footprints of lizard-like reptiles, as also of the great Labyrinthodont amphibians of the period. These impressions on the shore sands were after drying covered up with fresh sediments, and, in consequence of a continued slow depression, they were succeeded by other beds of the same nature, throughout a long series of deposits.

Other evidence of desiccated sand-banks is afforded by the sun-cracks on the planes of bedding. Annexed is an instance of this on the surface of a red argillaceous sandstone (fig. 72), where also the exposed surface had received the impress of the feet of a reptile that had passed over it. These last, however, are not well shown in the woodcut.

FIG. 73. *Relief casts of impressions of Cheirotherium footprints and Rain-drops. Trias, Storeton Hill, Cheshire.* (From photograph of a block, 4′ 6″ × 3′, in the Oxford Museum.)

Organic Remains are more abundant in the Keuper than in the Bunter, but they are still scarce, except in a few localities, and limited to Plants, Foraminifera, Crustacea (Estheriæ), Reptiles, and Amphibians, with a few Fishes. The tracks of Amphibians are far from uncommon in some places, especially at Storeton Hill, Weston, and Lymm, in Cheshire. The foot-prints are in some instances small and delicate; but others are large and ungainly. They mostly belong to Labyrinthodonts, and the larger tracks have been referred to an animal provisionally termed 'Cheirotherium,' from their peculiar similarity to the impressions of a huge mis-shapen human hand. They are generally in pairs, the fore feet smaller than the hind feet, the impressions of which latter are sometimes eight or more inches long (fig. 73).

There were several species of these great ungainly Labyrinthodonts, the skulls of some of which were 2 to 3 feet long, and covered by hard osseous plates; while the ventral part of the body was likewise protected by scales or plates. It is now thought that these animals were furnished with tails, and that their bodies were either salamandroid or frog-like in form, with relatively weak limbs.

Their remains may be distinguished by the peculiar sculpturing of the cranial bones, and by the character of the teeth. The skull articulated with the vertebral column by means of two condyles, as in all Amphibia, instead of by one, as in true Reptiles. But the most distinguishing feature is presented by the teeth, which externally are pointed and striated, and when sliced across exhibit a plaited and folded structure. This 'labyrinthic' pattern of the teeth has given the name to this order of Vertebrates. It is not observed in the teeth of Reptiles, although the structure of the teeth of the *Ichthyosaurus* is somewhat analogous. The teeth of some of the Labyrinthodonts are as much as two to three inches long, but they are generally smaller.

In the dolomitic conglomerate of Clifton, now known to be at the base of the Keuper, but once thought to belong to the Permian

'Magnesian Limestone,' Riley and Stuckbury discovered long since bones and teeth of two small Thecodont reptiles—the *Thecodontosaurus* and *Palæosaurus*,—which have both Lacertian and Dinosaurian characters. It is also in beds of this age, near Shrewsbury, that another and peculiar reptile has been found, termed *Rhynchosaurus* from its beak-like snout, probably without teeth, like that of the turtle. It is also in red sandstones of Triassic age near Elgin (originally supposed to belong to the Old-Red series) that the earliest Crocodilian type of reptile, *Stagonolepis*, was found, together with *Telerpeton* and *Hyperodapedon*. The peculiarity of the first of these two is its mixed Lacertian and Batrachian characters; the second, a reptile about 6 feet in length, is considered by Professor Huxley to be allied to a genus (Hatteria) now living in New Zealand.

Another important discovery has recently been made in the Elgin sandstone of a reptile belonging to the same order as the *Rhynchosaurus*, namely, the *Dicynodon*. Much interest attaches to this fossil, inasmuch as the genus, which was first found in the Karoo rocks of South Africa, and afterwards in the Panchet beds of India, had not before been met with in Europe. The jaws of this reptile form a kind of beak, and while the lower jaw is toothless, the upper jaw is furnished with two formidable outer tusk-like teeth.

There are a few fish remains in the Keuper, belonging to *Palæoniscus*, *Semionotus*, *Hybodus*, *Acrodus*, etc.; and marine Foraminifera abound in some beds, supposed to be Triassic, the most common being *Nodosaria*, *Dentalina*, *Flabellina*, and *Planularia*.

Besides these, there is only one small, but nevertheless important, Phyllopod Crustacean, the *Estheria minuta*, which is plentiful in some of the marl beds. This small shell-like crustacean belongs to a genus which now lives only in fresh or brackish waters, whence it has been held to confirm the view of some geologists, that most of these red rocks have been accumulated in fresh-water lakes, which gradually became, like the Dead Sea, salt in consequence of excess of evaporation.

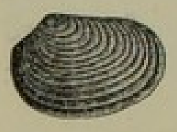

FIG. 74. *Estheria minuta*, Goldf., $\frac{2}{1}$.

The plant-remains of the Keuper in this country are scarce and indistinct. They consist of a few ferns, cycads, and conifers, of which latter the most notable is the *Voltzia heterophylla*, a tree allied to the recent cypresses, and common in the Trias of the continent. Fucoidal remains also occur.

Origin of the Red Colour. I do not, however, see cause for connecting these red rocks with deposition in fresh-water lakes. The colour in most cases may be due, not to the presence in the waters of the carbonate of iron and its subsequent peroxidation, but more probably to ferruginous kaolins or clays derived from the decomposition of the vast masses of porphyritic and basic igneous rocks poured out at the close of the Carboniferous, and during the whole of the Permian and Triassic periods. These kaolins formed in places argillaceous and marly beds, while at other places they either were mixed with, or else subsequently infiltrated into, the sandstones, and so coating the quartzose grains. Subsequent local de-oxidisation and changes in the condition of the iron-oxides, due to the presence of vegetable or organic matter, produced those variations in colour so conspicuous in the red clays and sandstones of these periods (Vol. I, p. 31).

FIG. 75. *Voltzia heterophylla*, Brongn.; Trias.

Causes of the Rarity of Fossils. It is possible also that if this be the origin of these red clays, it may be one cause of the rarity of fossils, for the waters may either have been de-aërated by the protoxides of the decomposed silicates of iron, lime, and magnesia, or they may have been injuriously affected by the alkaline salts set free by the decomposition of these minerals and of the felspars. To such causes I would attribute also the entire absence of fossils in the red and mottled clays of the Reading Series in the London, Hampshire, and Paris basins, as well as in the mottled clays of Wealden age in Kent and Sussex, all no doubt derived from old submerged lands of volcanic and crystalline rocks. For those parts of these seas or estuaries, over which such sediments did not extend, swarmed with life. In the same way it may be that the arkoses, derived from the decomposition of granitic and gneissic rocks, are so frequently barren of fossils, as in the case of the Millstone-grits of central England, the Permian rocks of the Estrelles and the Vosges, and the Lower Carboniferous rocks of central France.

There may be other contributory causes, such as that prevalent at the time of the Keuper Marls, when the extreme saturation and saltness of the waters would, as in the Dead Sea, have been fatal to animal life. We have evidence of amphibian life, of a land flora, and occasionally of fishes, but there is a general absence of aquatic invertebrate life, with the exception of the *Estheria minuta*. With respect to this small crustacean, I do not consider that its presence decides the question that the strata are of fresh-water or brackish-water origin, any more than the presence of land-plants or of land-shells washed out to sea proves the beds in which they occur not to be marine. As Professor Rupert Jones remarks, Estheriæ are quickly developed in pools or ponds of fresh water, which may be dry for many months of the year. They appear suddenly, and the free swimming species may be swept out to sea by a flood (or even by a heavy rainfall), or they may flourish temporarily during the alternate occupation of a lagoon by fresh or brackish water. That such must often have been the case is evident from the Table given by Professor Rupert Jones of the range of the Estheriæ in geological time, which shows that, although they naturally abound in the fresh-water or brackish Wealden strata, they also occur intercalated in beds of the Devonian, Carboniferous, Permian, and Jurassic formations[1].

It is evident, then, that there are various causes, whether taken separately or jointly, to which the scarcity of organic remains belonging to the Permian and Triassic periods may be attributed.

(1) Of these, the most important are the great hydrographical changes which locally affected so many areas in Europe and also in India at the commencement of and during the Permian period, but which do not seem to have affected the North American and Australian areas. The similar disturbances in Triassic times so frequent in Europe equally affected the North American area, while in the Indian area there seems little or no interruption in the sequence of the Permian, Triassic, or Jurassic strata.

(2) Another cause concomitant with this, is the vast mass of igneous rocks brought to the surface by submarine and subaerial eruptions during nearly the whole of these periods, together with the contributary influence which the products of decomposition of such rocks may have had when distributed amongst the sedimentary strata forming in the Permian and Triassic seas.

(3) Inasmuch also as the salt-deposits, although only local, are nevertheless associated very generally with these poikilitic formations in Europe, the presence of such saline solutions in so many areas cannot have failed to contribute to the general barrenness of life in the sedimentary deposits formed under such conditions.

(4) Nor must we overlook the suggestion of there having been a glacial period in Permian times, for a great climatal change of that character must have been widely destructive to the life of that period; but, as before observed, this remains for the present an open question.

Need we then wonder, looking at these many contingencies, at the

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1 'The Monograph on the Fossil Estheriæ' (Palæont. Soc. Monogr. for 1862) by Professor Rupert Jones is a model of what such a monograph should be. The author gives the habitats and geographical distribution of all the living species, and describes and figures all the then known fossil species throughout the geological series both in England and in other countries where they have been found, so that the information is complete on all points.

pauperised fauna,—the alteration of the flora,—the destruction of so many forms,—and the extensive modifications among the few that survived?

The Rhætic Beds. Overlying the red series, and underlying the Lias in south-western and central England, is a group of dark-grey and black shales, alternating with thin beds of white argillaceous limestone, which were formerly supposed to constitute a local and subordinate division at the base of the Lias, but now, on the evidence of organic remains, placed at the top of the Trias[1]. These strata are the equivalents of a formation largely developed in some parts of the Continent, especially in the Tyrol and the Rhætian Alps, whence the term 'Rhætic' by which it is known.

In England its development is small, varying from 50 to 100 feet; but the organic remains are important, and form a marked geological zone. Beds of this age are well exhibited in the cliffs at Penarth near Cardiff; also in the fine cliff sections at Westbury-on-Severn and Aust Passage near Bristol. A great feature are the bone-beds, which constitute one or more thin, but very extensive, pyritic layers full of broken and worn reptilian bones, with fish-teeth and scales in small fragments. Some of the upper shales and marly limestones are rich in remains of Molluscs, Entomostraca, and Insects.

The Plant remains, which occur in the cliff at Wainlode, are mostly fucoidal and indistinct; but there have been found at Westbury-on-Severn, and elsewhere, other specimens referable to *Naiadita* (fig. 76, *d*), *Cupressus*, etc.[2]

Insect remains. Neuropterous insects, including species of *Libellula* or dragon-fly; Orthopterous insects related to *Blatta* (cockroach), *Gryllus* (grasshopper); and the elytra of beetles, are not uncommon. They are all allied to existing genera, and, according to Professor Westwood, they resemble forms 'of temperate climes more like North America than Europe[3].' They often occur in clotted masses, as though carried down by a stream. A variety (*Brodieana*) of the small crustacean *Estheria minuta* so common in the Keuper is very characteristic of one horizon in the Rhætic. Ostracods are also abundant in some of the beds.

The Mollusca are very characteristic, and it is noticeable that they are of small size or dwarfed. The most common species is a bivalve, the *Avicula contorta*, which from its abundance, at first gave its name to these beds. This fossil was discovered and named by the late General

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[1] 'Zones of the Lower Lias,' etc., by Charles Moore, Quart. Journ. Geol. Soc., vol. xvii. p. 483; and vol. xxiii. p. 449.

[2] J. Buckman, 'On some Fossil Plants from the Lower Lias,' Q. J. Geol. Soc., vol. vi. p. 413.

[3] Brodie's 'Fossil Insects,' pp. xv. and 58.

Portlock[1], who recognised the independence of this group in the strata of Portrush in the north of Ireland. The other common shells are:—

Ostrea liassica, *Strickl.*	Pullastra arenicola, *Strickl.*
Pecten Valoniensis, *Defr.*	Cardium Rhæticum, *Merian.*
Monotis decussata, *Goldf.*	Pleurophorus elongatus, *Moore.*
Modiola minima, *Sby.*	Discina Townshendi, *Forbes.*

Though the species of Mollusca are few, the number of individuals is very great, and they seem to indicate shallow and often brackish waters, and the near proximity of land. It is interesting also to observe that in the English strata there are no brachiopods, no cephalopods, no corals. Of Echini there are locally abundant spines.

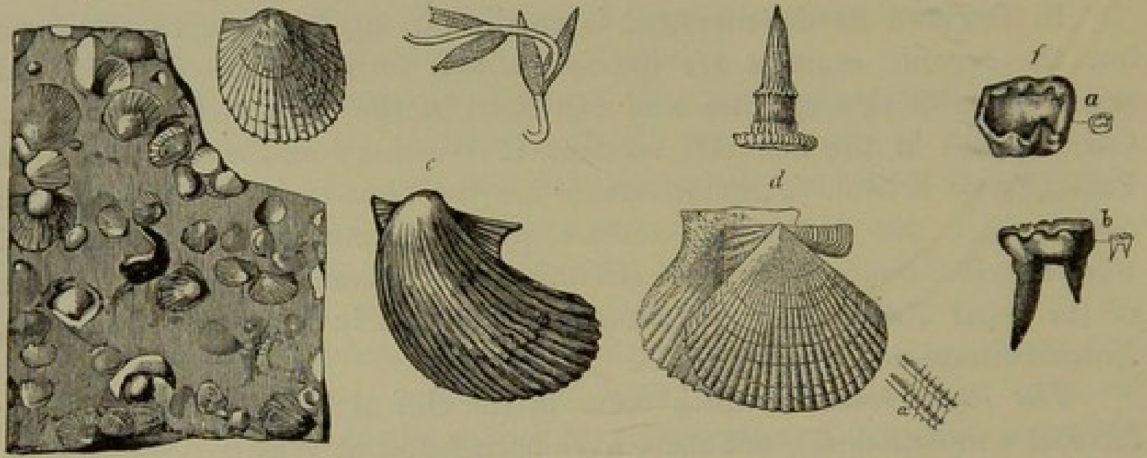

FIG. 76. Rhætic Fossils.
a. Naiadita lanceolata, Brod. *b. Monotis decussata*, Goldf.: *b'.* enlarged. *c. Avicual contorta*, Portl. *d. Pecten Valoniensis*, Defr. *e. Tooth of Saurichthys apicalis*, Ag. *f. Tooth of Microlestes Moorei*, Owen. *a, b*, nat. size.

The remains of *Fishes* are abundant, but they are almost always in small fragments; the 'bone-bed' is full of the teeth and scales of *Hybodus*, *Gyrolepis*, *Ceratodus*, *Acrodus*, *Nemacanthus*, and *Saurichthys*. The occurrence of the *Ceratodus* is of special interest, as the genus still survives in the *Barramunda* of the rivers of Queensland.

Reptiles. It is at the insetting of the Rhætic that the great group of the large Enaliosaurians first make their appearance in Europe. Teeth, vertebræ, and other bones, usually much rolled and worn, of Ichthyosaurus and Plesiosaurus are common in the bone-bed at Aust Passage and other places.

Mammalia. The fossils, however, which are of most special interest, are the remains of the *Microlestes antiquus*, a small marsupial allied to the insectivorous *Myrmecobius* of Australia. Teeth and vertebræ of the *Microlestes* were found in large numbers by the late Mr. Charles Moore among Rhætic débris filling crevices of the Mountain Limestone near Frome in Somerset. So abundant were the smaller fossils,

[1] See his 'Geological Report on Londonderry' for description of the strata and the fossils.

that washing a portion of three cart-loads of the soil taken out of one of these fissures, he was able to exhibit twenty-nine teeth of Microlestes, fragmentary remains of nine genera of reptiles, and of fifteen fishes, including 70,000 teeth of Lophodus; and he estimated that the whole quantity would probably have yielded him a million specimens[1]! Professor Boyd Dawkins found a similar tooth (named by him Hypsiprimnopsis) *in situ* in the passage shales of the Upper Keuper of Watchet, Somerset. Much importance attaches to these small creatures, as (with the specimens at Stuttgart) they are the oldest land mammals yet discovered in Europe.

At several localities, the surface of the Rhætic beds is eroded, and occasionally drilled by boring shells, showing that there was a slight break between them and the lower division of the Lias, which overlies these Rhætic, or Penarth beds as they have been called by Mr. Bristow.

Thin layers of grey argillaceous limestone, in the upper part of this group of strata, or at the base of the White Lias, furnish, when cut and polished in vertical sections, the well-known 'Landscape marble' of the Bristol district.

FOREIGN EQUIVALENTS.

France. Conglomerates similar to those which we have noticed at Budleigh-Salterton, associated with sandstones and red marls of no great thickness, occupy a small area in Normandy (Cotentin). New Red Sandstones also occur in the Auxois; and, in the neighbourhood of Macon and of Autun, there are thick beds of arkose of the same age. Triassic strata also exist in Provence; and in the Pyrenees they form a mass of variegated red sandstones and conglomerates about 2000 feet thick, surmounted by dolomites and mottled clays with beds of gypsum.

The Trias is again largely developed in the Western Alps, where it consists mainly of quartzites and schistose beds with gypsum. The salt-beds of Bex are of this age. The fossils of the Trias are in general scarce, except in the middle division or Calcaire Conchylien, and in parts of the Keuper. In the former, *Encrinus liliiformis*, *Myophoria vulgaris*, etc. occur; and in the latter, species of Cypricardia, Avicula, and Posidonomya, with Labyrinthodont footprints.

Germany. In the Vosges, the Trias succeeds conformably to the Permian. The lower division consists of an unfossiliferous red sandstone (Grès des Vosges) with thick subordinate beds of conglomerates, consisting of rounded pebbles of white quartz and grey or reddish quartzites, some of considerable size, but no boulders. These are surmounted by variegated sandstones (Grès bigarré), with *Voltzia heterophylla*, *Equisetum*, *Pecopteris*, etc. To these succeed the Muschelkalk with its characteristic fossils.

[1] 'Brit. Assoc. Reports for 1864.'

The Keuper consists of variegated red, blue, grey, yellow, and green marls, accompanied by beds of gypsum, anhydrite, and rock-salt. With these are associated beds of red sandstone and of dolomite. Plant remains are abundant in some parts of the Trias,—*Clathopteris Munsteriana* and *Pecopteris Stuttgartensis* being very characteristic. But the predominant plants are Cycads of the genera Pterozamites, Pterophyllum, and Otozamites, whilst among the Conifers the characteristic form is the *Voltzia heterophylla*. The fauna is poor; amongst the characteristic shells are *Gervillia socialis*, *Lingula tenuissima*, *Terebratula vulgaris*, and *Myophoria costata*. The *Estheria minuta* is also common. Some of the beds are full of the remains of fishes, such as *Semionotus*, *Acrodus*, *Hybodus*, *Saurichthys*, and *Ceratodus*, with Labyrinthodonts and Saurian reptiles of a higher order (Nothosaurus and Mastodonsaurus—*M. Jageri*) than at that period existed in this country. The Keuper of Lorraine is rich in beds of salt and gypsum, the intercalations of these minerals being frequent. (See section, *ante*, p. 161.)

The Halstatt, St. Cassian, and Esino Beds. The Trias extends into Thuringia, Würtemberg, the Hartz, and the Tyrol. It is in this last and in the adjacent Alpine districts that the intercalation of the St. Cassian and Halstatt beds occurs. They consist of red and white limestones some 800 to 1000 feet thick, containing a remarkable mixture of Palæozoic genera (the species, however, not being the same), such as *Orthoceras*, *Bellerophon*, *Murchisonia*, *Euomphalus*, associated with *Ceratites*, *Ammonites*, *Opis*, *Gervillia*, *Monotis*, and other Mesozoic forms. It is a very interesting instance of the reappearance of a Molluscan fauna which had apparently become extinct in Western Europe, but which, surviving elsewhere, came back from that area, where the disturbances to the continuance of life had been less, and intermingled with the newer Mesozoic genera, which in the other area had directly succeeded the original population. It is not the re-appearance of a few stray individuals, but of an important colony, with a rich fauna of about 500 species. Amongst some of the most typical Mollusca are *Ammonites Aon*, *Halobia Lommeli* (which gives the name to one division), *Orthoceras dubium*, *O. alveolare*, etc.

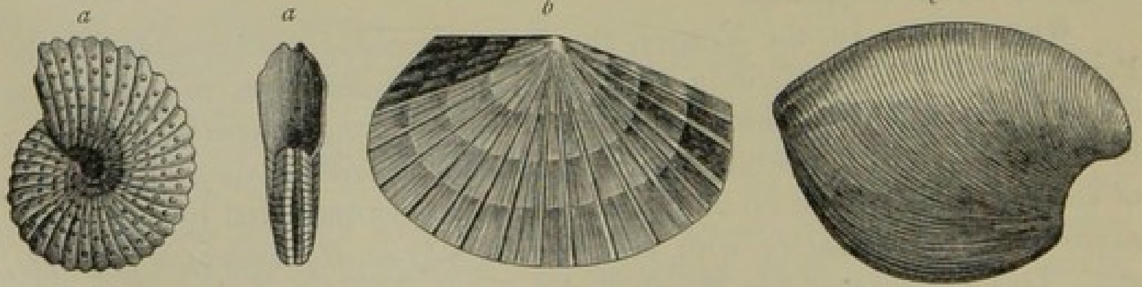

FIG. 77. *a. Ammonites Aon*, Münst. *b. Halobia Lommeli*, Wissm. *c. Megalodus triqueter*, Wulf.

The Rhætic or Kössen Beds. Whereas in this country the

Rhætic is a thin littoral and brackish-water deposit, in the Tyrol it is mainly a deep-sea deposit, consisting of calcareous shales at Kössen and of thick limestones in the Dachstein mountains of Styria, and is rich in organic remains. The characteristic fossils are *Avicula contorta*, *Pecten Valoniensis*, *Gervillia inflata*, *Terebratula gregaria*, *Spirigera oxycolpos*, *Megalodus triqueter*, and a peculiar coral of the *Lithodendron* group. The Rhætic formation extends also to parts of Bohemia, Saxony, and Hanover, and is everywhere characterised by very much the same fossils, the *Avicula contorta* being generally so abundant as to have given its name to this geological zone. It was in a bone-bed of this age in Würtemberg that teeth of the Microlestes were first found by Plieninger in 1847. The thin bone-beds are as persistent over large areas as they are in this country.

North America. At the close of the Permian period there were in North America, as in Europe, great disturbances and great dyke eruptions, which were prolonged far into the Triassic period. The break between the two series, and the amount of denudation, are as marked in America as in Europe. The rocks also commonly consist of red sandstones with shales and conglomerates, and oblique lamination is frequent; but, while there is a marked distinction between the Permian and Trias, the Trias seems to pass upwards without break into the Jurassic series. Many of the sandstones are finely laminated and covered in places with ripple-marks, sun-cracks, rain-drop impressions, and footprints of reptiles, beautifully preserved.

On the Atlantic border, and in the western interior, the Trias is remarkable for the paucity of all evidence of marine life, but on the Pacific slopes there are many marine fossils (Dana).

The Carboniferous flora has disappeared, and is replaced by new forms of ferns, cycads of the genera *Pterophyllum* and *Podozamites*, and conifers of the genus *Voltzia*, one species being very closely allied to the *V. heterophylla* of Europe. In Virginia and North Carolina vegetable life so abounded as to have formed Coal-measures of considerable importance, 800 to 1200 feet thick, and with four or five seams of workable coal. Insects, indicating the proximity of land, and Entomostraca, including species of Estheria, with a few ganoid fishes, are also met with.

In California and Nevada the fauna exhibits, as at Halstatt, the same remarkable association of Palæozoic with Mesozoic forms. Species of Spirifer, Orthoceras, and Goniatites occur with Ceratites, Monotis, and Myophoria.

It is especially in the Connecticut valley that footprints are found. The great majority are tridactyle, and were originally supposed to belong to birds, but they are now generally referred to Amphibia, or possibly to land Reptiles,—Dinosaurs (*Bathygnathus*, *Amphisaurus*, etc.), of which some bones have been found in the same beds. These prints vary in size from ¼ inch to 20 inches in length,—some showing a stride of 4 feet. Professor Hitchcock, by whom they have been described, recognised as many as fifty species, several of which must have been animals of gigantic size. Many thousands of these tracks have been exposed. Reptiles of Crocodilian and Enalosaurian types have also been met with.

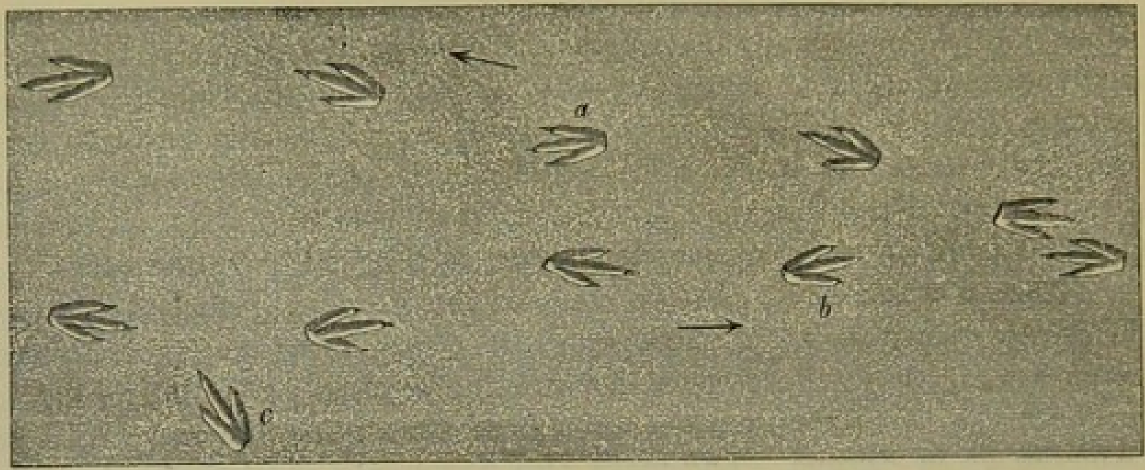

FIG. 78. *Reptilian Footprints* (*Ornithichnites*, Hitchc.), *New Red Sandstone, Connecticut Valley. a, b, c, represent three different sets of tracks.*

It is in these strata likewise that the oldest American mammal—the *Dromatherium sylvestre*, a small insectivorous marsupial resembling the Microlestes—was found by Professor Emmons.

India. We are informed by Messrs. Medlicott and Blanford, that, while the Lower division of the Gondwána system of Peninsular India, which consists of Upper Palæozoic (Permian) and Triassic strata, is separated by a great break from the older Palæozoics (the Vindhyan), there is good reason for supposing that it is intimately connected with the Upper Gondwána beds, which are certainly Mesozoic[1]. The upper division of the Lower Gondwánas consists of the Panchet series, formed of grey and greenish sandstones with red clays and conglomerates. Ferns of the genera Pecopteris, Cyclopteris, and Tæniopteris, two of them being of European Triassic species, together with Equisetaceæ of the genus Schizoneura (also a Triassic and Rhætic genus), occur in these beds. The fauna consists of Labyrinthodonts (*Gonioglyptus*) allied to Mastodonsaurus, and of Dinosaurian reptiles and Dicynodon, while a small species of Estheria (*E. mangaliensis*) is common[2].

In the extra-Peninsular area, rocks of supposed Triassic age with Ceratites and Orthoceratites exist in parts of the Salt Range, and extend as far as the Mustágh range; they are also met with eastward as far as Burmah. There are some higher beds which have been referred to the Rhætic[3]. The Pára limestone of Hazára contains *Dicerocardium Hima-*

1 'Manual of the Geology of India,' pp. xiv, xxviii.
2 *Ibid.* p. 132.
3 *Ibid.*, pp. vi. and 636

layense, and *Megalodon triqueter*, the latter characteristic of the Dachstein limestone of the Austrian Alps. Above this comes the Tagling limestone with a fauna allied to that of the Kössen beds, amongst them being *Pecten Valoniensis*, *Terebratula gregaria*, *Avicula*, *Arca*, etc.[1] In the Liláng limestones of the Zánskár area of Tibet, the *Halobia Lommeli* of the Alpine Trias abounds, together with *Myoconcha Lombardica*, *Monotis salinaria*, and species of *Spirifera*, *Orthoceras*, *Ammonites*, etc. The Halobia is again met with in Burmah.

A remarkable feature of the Triassic strata of the North-west Himalayas is the similarity of the fauna throughout the whole series to that of corresponding beds in the Alps. The sub-divisions of the strata do not precisely correspond, but the community of specific forms is such as to render it highly probable that the seas of the two areas must have communicated together during that period[2].

Australia. The Australian geologists refer the Hawkesbury series to the Trias and the Wianamatta series to the Jurassic, while, as before mentioned, the Indian geologists think it more probable that the former at all events is of Permian age. The fossils, however, are so few, consisting chiefly of plants of the genera Zamites, Pecopteris, Tæniopteris, with only a Unio and a few fishes related to the genus Palæoniscus, that the question is difficult to decide upon.

South Africa. The most important formation of South Africa is that termed the Karoo series, which consists of sandstones and shales 8000 to 10,000 feet thick, and extensively traversed by dykes of igneous rocks. The sandstones are rich in Dicynodont and other reptilian and amphibian remains. The Karoo Beds also contain ferns (Pecopteris, Glossopteris, Tæniopteris, with cycads—Otozamites, Pterophyllum, etc.) and a conifer. Amongst the fishes are species allied to Palæoniscus and Amblypterus. It is in the upper beds of this series that a small mammal about the size of a fox has recently been found. Owen [3], who considers its affinities to point in one direction to marsupials and in another to rodents, has named it (from the tricuspid crowns of the teeth) *Tritylodon longævus*.

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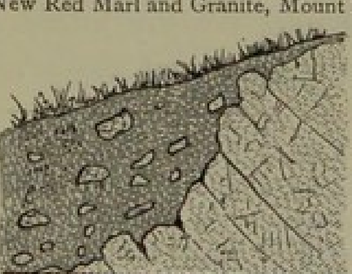
[1] Dr. Blanford now places the Rájmahál beds with the Rhætic. [2] 'Geology of India,' p. xlvii.
[3] 'Quart. Journ. Geol. Soc.,' vol. xl. p. 146.

Junction of the New Red Marl and Granite, Mount Sorrel; see p. 159.



CHAPTER XII.

THE JURASSIC SERIES: THE LIAS.

Range and General Characters. The Liassic Strata. The White Lias. Organic Remains. The Lower Lias. The Middle Lias or Marlstone. Iron-ore of the Marlstone. The Upper Lias. The Midford Sands. Jet. Iron-pyrites. Alum-shales. Organic Remains. Plants. Foraminifera. Corals. Echinodermata. Annelids. Crustacea. Insects. Molluscoidea and Mollusca. Characters of the Ammonitidæ. Ammonite-Zones. Structure of Belemnites. Fishes. Reptiles; Ichthyosauri; Plesiosauri; Pterodactyles. Profusion of Life. Palæontological Character of the Midford Sands.

Range and General Characters of the Jurassic Series. We had to deal in the last chapters with the great Triassic series of red sandstones, marls, and conglomerates, which constitute so marked a feature in Cheshire, Shropshire, Warwickshire, Worcestershire, and the south of Devonshire. We now have to deal with another group of rocks, the Jurassic, equally distinct, and equally well-marked as the preceding by their petrological and palæontological characters, consisting as they do of thick deposits of dark clays, indurated marls, argillaceous limestones, and light-coloured oolitic rocks, with some sand-beds and subordinate sandstones. The predominating strata in the lower part are dark clays and marls, and in the upper portion light-coloured shelly and oolitic rocks. These together constitute the Jurassic series, and extend from the Rhætic beds of the Trias to the base of the Cretaceous series, with a maximum thickness in England of from 3000 to 4000 feet.

The Liassic Strata. The first or lowest Formation of this series is the Lias; a provincial name which has been adopted by geologists. It is divided into three groups,—the Upper Lias, the Middle Lias or Marlstone, and the Lower Lias. The Lias ranges in a broad belt from the coast of Dorsetshire, across England, to the coast of Yorkshire. The cliffs of Lyme Regis and Whitby afford sections which have long been classical for their stratigraphy and fossils[1].

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[1] See for a description of the Lias in the south and centre of England, De la Beche, 'Trans. Geol. Soc.' 2nd ser. vol. i. p. 40, and vol. ii. p. 21; Phillips's 'Geology of Oxford'; Wright's 'Lias Ammonites' (Introductory Notices), Palæont. Soc., Monogr. for 1878-79; Judd's 'Geology of Rutland,' Mem. Geol. Survey; and for the north of England, Phillips's 'Geology of Yorkshire,' vol. i; and Tate and Blake's 'The Yorkshire Lias.'

The White Lias. There is still some uncertainty where the line between the Rhætic or Penarth and the Liassic groups should be drawn. Some geologists would include the White Lias and the Sutton beds in the Rhætic; others would place one or both of these in the Lias. Some of the Rhætic fossils, such as *Ostrea Liassica, Monotis minima*, and *Pecten Valoniensis*, pass upwards into the White Lias. On the other hand, the *Avicula contorta* and other characteristic Rhætic forms of the underlying group do not pass up. Further, the Sutton beds contain, according to Professor Duncan, a group of corals distinctly different from anything Rhætic, and occurring

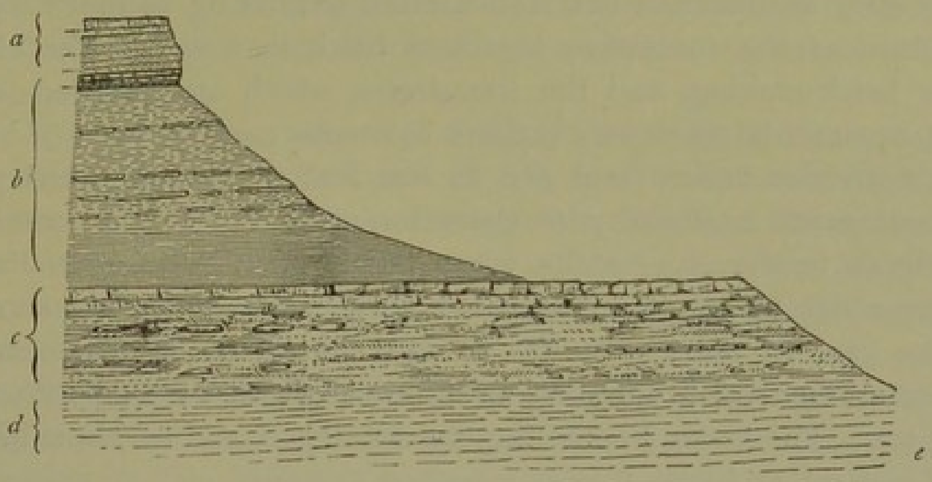

FIG. 79. Section of Frocester Hill near Stonehouse, Gloucestershire (Wright).
a. Inferior Oolite, 70 ft. b Upper Lias Sands and Clay, 230 ft. c. Middle Lias (Marlstone), 105 ft. d. Lower Lias. e. New Red Sandstone.

on the Continent at a higher horizon than that of the *Avicula contorta*, while they are certainly distinct from the few Liassic species proper. Amongst them are *Montlivaltia polymorpha*, Termq., *Thecosmilia rugosa*, Laube, etc.[1]

These beds are apparently passage-beds, setting in with the subsidence of the Rhætic areas, and the introduction of the deeper-sea Liassic fauna. Should we not therefore group together the White Lias, Sutton-stone, and the *Ammonites planorbis* zone, and place them on the horizon of the Hettangian beds of the French geologists as under?

Infra-Lias.	A. planorbis Zone.	*Ammonites planorbis, Ostrea Liassica, Protocardium Phillipsianum, Unicardium cardoides, Lima pectinoides, L. gigantea, Modiola minima.*
	White Lias and Sutton-Stone Beds.	*Ammonites angulatus, Lima gigantea, Pleurophorus angulatus, Modiola minima, Ostrea Liassica, O. irregularis, Plicatula interstriata, Lima precursor, Avicula decussata, Pecten Valoniensis, Cardium Rhæticum, Monotis decussata, Montlivaltia polymorpha, Thecosmilia rugosa.*

The question, however, is complicated, and the student will do well

[1] Besides a number of new and peculiar species, described by Prof. P. Martin Duncan, 'Quart. Journ. Geol. Soc.' xxiii. p. 12.

to consult the various papers by Wright[1], Moore[2], Dawkins[3], Tawney[4], Duncan[5], and Bristow[6] on this subject.

The White Lias consists of light-brown and grey impure limestones and grey shales, weathering white. Locally, it is capped by a hard fine-grained, almost lithographic limestone (Sun-stone), and is underlain by a conglomerate of Carboniferous-limestone pebbles. The *Planorbis*-zone consists of dark shales and clays with bands of impure grey limestone and marls.

The Lower Lias, which we take to commence with the *Ammonites Bucklandi* zone, consists of alternating beds of dark clays, shales, and thin layers of grey argillaceous limestones, often exhibiting as much regularity of structure as the successive layers of brick in a wall. The clays are used for brick-making, and the limestones, which are quarried for lime-burning, commonly make an excellent hydraulic cement.

This division varies from 500 to 800 feet in thickness, and presents throughout much uniformity of character, except where it passes transgressively on to the older rocks, when its approach to a former Palæozoic coast gives rise to conglomerate beds, formed along the old shore-lines, as in the case of the Carboniferous hills of South Wales, near which conglomerate beds of Mountain-limestone pebbles form the basement-beds of the Lias. The lower Lias is largely developed and very fossiliferous in the cliff sections at Lyme Regis.

In the second division of the Lias, namely the *Marlstone*, a considerable change takes place in the petrological structure of the rock. In Dorsetshire it consists of grey clays, marls, and sandstones, with some brown sands, together about 350 feet thick. In the neighbourhood of Cheltenham, this division consists essentially of clays and marlstones, with a lower variable series of brown, yellow, and grey sands and shales, altogether about 150 feet thick. In the central and northern districts of England the marlstone becomes charged with iron-oxide or carbonate, so much so that the rock is often largely worked as an *iron-ore*. In Oxfordshire, where the marlstone is from twelve to twenty feet thick, it consists almost entirely of a dark greyish-green rock, containing fifteen to thirty per cent. of iron. It is worked to some extent at Fawler near Charlbury, and at Deddington, King's Sutton, and other places near Banbury.

As we proceed northward the iron becomes more abundant, and in the Cleveland district of Yorkshire it is present in such large proportions that of late years these strata have given rise to some of the most extensive iron-works in the kingdom. The marlstone there is 138 feet thick, and contains sixteen beds of ironstone, some of them of considerable thickness.

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[1] 'Quart. Journ. Geol. Soc.' vol. xvi. p. 347.

[2] *Ibid.*, vol. xvii. p. 483; and vol. xxiii. p. 449.

[3] *Ibid.*, vol. xx. p. 396.

[4] *Ibid.*, vol. xxii. p. 69.

[5] *Ibid.*, vol. xxiii. p. 12.

[6] *Ibid.*, vol. xxiii. p. 199.

In general appearance, this ironstone looks like an ordinary calcareous green sandstone, is often oolitic, and sometimes very fossiliferous. When exposed to the air and water, these rocks weather brown, owing to the decomposition of the iron-carbonate and its conversion into the peroxide.

Together with varying proportions of lime, alumina, magnesia, and silica this ore contains a certain proportion of phosphoric acid and sulphur, which seriously interfere with the quality of the iron. The phosphoric acid is no doubt due to the animal matter of the fossils, which often abound in these rocks. It takes about three tons of the better qualities of this ore to make a ton of pig-iron; but, whereas some samples yield as much as thirty-four per cent. of metallic iron, others do not contain more than thirteen per cent.

The Upper Lias, very thin (under 100 feet) in Dorsetshire and Somersetshire, attains a thickness of 300 feet in Gloucestershire; and continues in varying dimensions through the Midland Counties to the Yorkshire coast near Whitby, where it is about 200 feet thick. This division consists of dark-grey clays, shales, and marls, with bands of septaria and impure limestones.

The **Midford Sands.** In the South of England a mass of yellow quartzose sands, with occasional bands of calcareous concretionary sandstone, passing in the Midland Counties into a dark brown ferruginous fossiliferous rock, separates the Upper Lias from the Oolitic strata. These sands, which are nearly 200 feet thick on the coast at Bridport, and 150 feet in Somersetshire, diminish to twenty or thirty feet in Gloucestershire, while further north they rarely exceed a few feet in thickness.

These beds were formerly known as the 'Sands of the Inferior Oolite,' but, although they show some palæontological relation to the Oolites, the late Dr. Wright[1] considered that they should be grouped with the Upper Lias. Professor Phillips proposed for them the name of 'Midford Sands.'

Iron-pyrites is very common in the Upper Lias, where it is found segregated around wood, Ammonites, Belemnites, and Pentacrinites. As this iron-pyrites contains as much as sixty-three per cent. of sulphur, it has occasionally been worked for that mineral.

The Upper Lias of Yorkshire also contains certain shales known as Alum-shales, which have long been worked for the manufacture of alum.

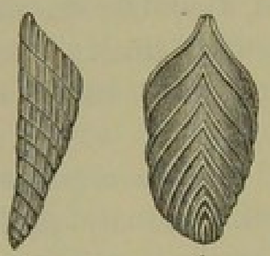
It is likewise from the cliffs of the Upper Lias, chiefly near its base, that the *jet* of the Yorkshire coast is obtained. This jet is wood converted into a sort of cannel coal; but, whereas coal was formed from wood which belonged chiefly to a Cryptogamic vegetation, jet has been formed from coniferous wood, allied to the Araucarian pines, the structure of which

[1] 'Quart. Journ. Geol. Soc.' vol. xii. p. 292.

can often be detected when thin sections of jet are placed under the microscope. This wood also did not, as with the coal, grow on the spot and become subsequently submerged; but it was drifted out to sea, and sank, water-logged, to the bottom, amidst Ammonites, Belemnites, and other marine fossils. As the cliffs gradually fall the jet is now washed out and strewed over the shore.

Organic remains. The novelty and profusion of the fossils of the Lias invests this fauna with peculiar interest.

Plant remains are not abundant. Cycadaceæ of the genera *Cycadites*, *Otozamites*, *Zamites*, *Pterophyllum*, *Nilssonia*, and *Palæozamia* predominate. Some species occur in the shales and marls of Lyme Regis, together with a few Ferns of the genera *Camptopteris*, *Thaumatopteris*, etc., and some coniferous wood belonging to *Araucarites*, *Brachyphyllum*, *Peuce*, *Thuites*, etc. (For the Mesozoic families of plants, see the Great Oolite, p. 198.)



a *b*

Fig. 79*. *a*. *Planularia Bronni*, Roemer, $\frac{20}{1}$. *b*. *Frondicularia complanata*, Defranc. (variety), $\frac{20}{1}$.

Foraminifera. Species of *Planularia*, *Frondicularia* (Fig. 79*, *a*, *b*), *Nodosaria*, *Cristellaria*, *Polymorphina*, *Spirillina*, are not generally common, though they are abundant in some places.

Corals are, as a rule, scarce, as might be expected from the prevalence of clay-beds unfavourable to the growth of corals, which require clear water. But though there is only one species in the Lower Lias, and two in the Middle Lias, Prof. P. M. Duncan has found sixty-four species in the Upper Lias, belonging chiefly to the genera *Montlivaltia*, *Thecosmilia*, and *Rhabdophyllia*.

Neither are the ordinary **Echinoderms** common; *Hemipedina Etheridgii* (Pl. VIII, fig. 1) is a characteristic but rare species. But Crinoids are plentiful; and one abundant form, the *Extracrinus Briareus*, is known to all collectors. This profusely jointed species consists of a long column, that was often attached to pieces of floating wood, surmounted by a body with innumerable arms and tentacles. It is to this circumstance that it owes its name after the many-armed giant of classical fable. The number of ossicles or joints in the column and arms of this Crinoid are estimated at not less than 150,000.

Another order of Echinodermata, one intermediate between the true Star-fishes and the Crinoids, namely, the *Ophiuroidea*, is common in the Lias. These first made their appearance in Silurian times, but are scarce until we reach the Lias. They are easily recognised by their five arms with a central disc, which latter is wanting in the true Star-fishes. From the Liassic period up to the present time they continue abundant, and they mostly belong to existing genera. A characteristic form in the Lias, especially the Middle Lias, is the graceful *Ophioderma Egertoni*. True Star-fishes also occur, but they are by no means so characteristic.

The **Annelids** of this period are not of any importance.

On the other hand, **Crustacea** appear in some variety; but they are

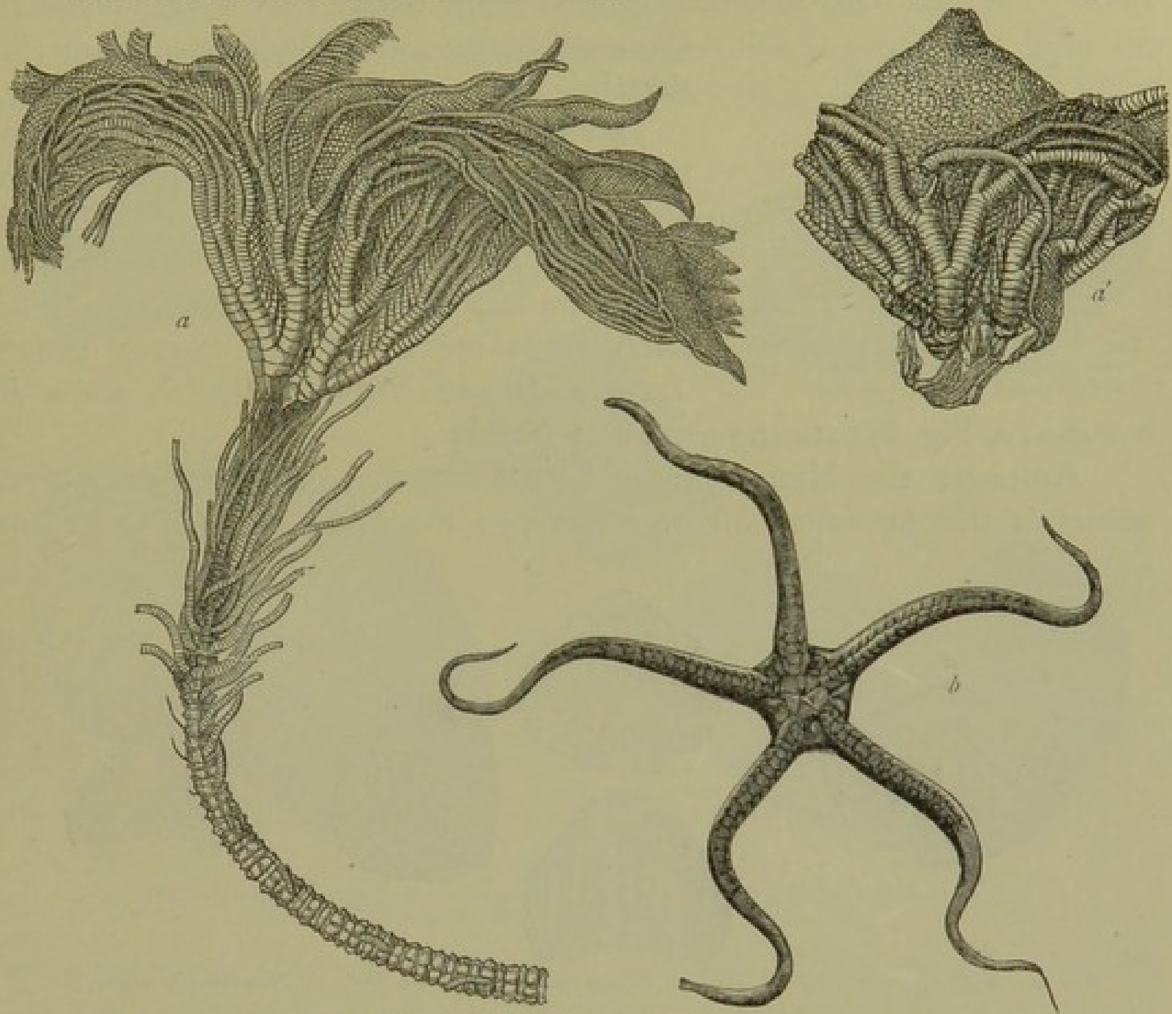


FIG. 80. Echinodermata of the Lias.
a. Extracrinus Briareus, ½; *a'. Head of the same without the tentacles* (after Buckland). *b. Ophioderma Egertoni*, Broderip.

of a kind very different from those which we have had to notice in the Palæozoic rocks. Of the large orders, *Trilobita* and *Eurypterida*, not a trace remains. Macrurous *Decapods*, to which belong our present lobsters and prawns, are common; but none of the Brachyurous Decapods, to which the recent crabs belong, have yet made their appearance. Species of the macrurous genus *Eryon*, together with species of *Palinurina*, *Glyphea*, and *Scapheus*, are very characteristic of the Lias. Minute Ostracod crustaceans are also plentiful in places.

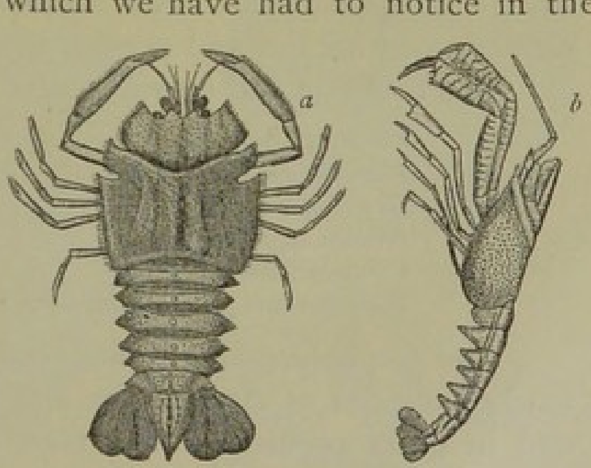


FIG. 81. Crustacea of the Lias.
a. Eryon Barrovensis, M'Coy. *b. Glyphea liassina*, Meyer.

The remains of **Insects** belonging to the Neuroptera or insects with open-nerved wings, like the dragonfly, and to the Coleoptera or beetle tribe, with relics of others, are not uncommon in some particular beds of the Lias. They are most abundant in beds of the Upper Lias of Dumbleton in Gloucestershire, and at Bidford in Warwickshire[1].

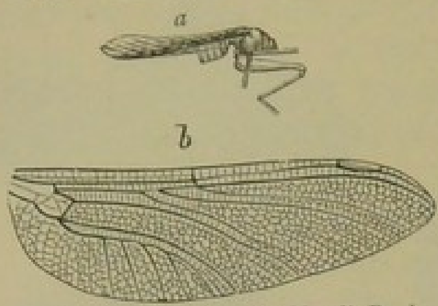


FIG. 81*. *a. Gryllus Bucklandi*, Brod., with dislocated leg. *b.* Wing of *Libellula Brodiei*, Buckm. (Brodie).

Brachiopoda and Mollusca. Brachiopoda are no longer the predominating class, although still common. The family of *Spiriferidæ*, so abundant in Palæozoic times, now makes its last appearance (*Spiriferina Walcotti*), while species of the existing genera *Terebratula* and *Rhynchonella* (*R. acuta*, *R. tetrahedra*, Fig. 82) are the prevailing forms.

Amongst the Monomyarian Lamellibranchs, the *Gryphæa incurva* occurs in this formation all over Europe; the *Lima gigantea* and *Plicatula spinosa* are also characteristic. In the Dimyarian division species of *Modiola*, *Lima*, and *Avicula* are very abundant; many genera now make their first appearance. The *Hippopodium* is confined to the Lias. The Gasteropoda are few and present little to notice.

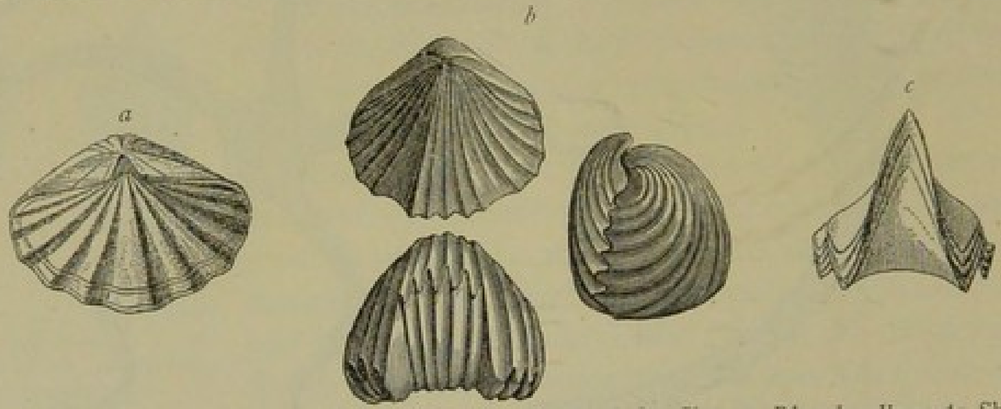


FIG. 82. *a. Spiriferina Walcotti*, Sby. *b. Rhynchonella tetrahedra*, Sby. *c. Rhynchonella acuta*, Sby.

The common and characteristic species of the above are:—

Lima gigantea, *Sby.*	Modiola scalprum, *Sby.*
Plicatula spinosa, *Sby.*	Pholadomya ambigua, *Sby.*
Gryphæa incurva, *Sby.*	Unicardium cardioides, *Phil.*
Avicula cygnipes, *Phil.*	Monotis decussata, *Goldf.*
Cardinia Listeri, *Stutch.*	Pleurotomaria Anglica, *Sby.*
Hippopodium ponderosum, *Sby.*	,, expansa, *Sby.*

The Cephalopoda are singularly abundant and characteristic; well-marked species of Ammonites and Belemnites occurring in great variety and in great profusion. No true Ammonites older than the Lias are known in England. Hence they range upwards throughout the Mesozoic formations, and only end with the Chalk. Above five hundred species have been described, and are divided into six sections according to characters

[1] See Brodie's 'Fossil Insects,' chapter iii.

connected with the form of the back, and these again are subdivided into twenty groups.

Ammonites are distinguished from other *Ammonitidæ* and from the *Nautilidæ* by the following prominent characters: 1. The siphuncle (*a*) or

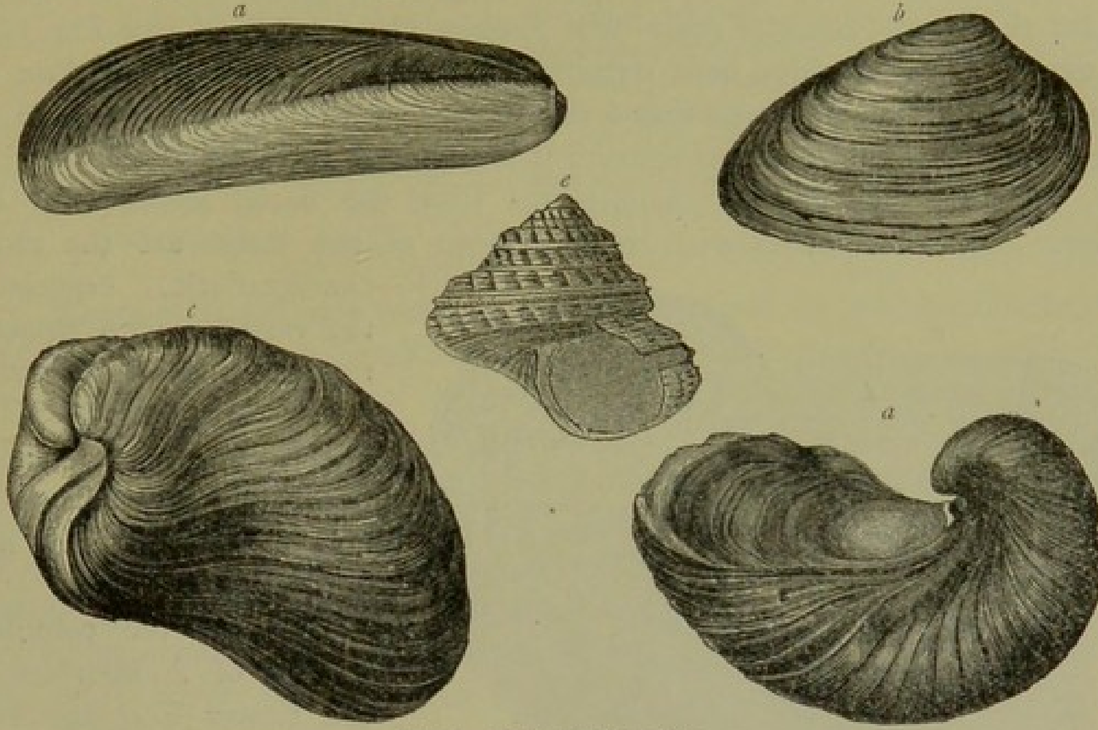


FIG. 83. Mollusca of the Lias.
a. Modiola scalprum, Sby. *b. Cardinia Listeri*, Sby. *c. Hippopodium ponderosum*, Sby. *d. Gryphæa incurva*. Sby. *e. Pleurotomaria Anglica*, Sby.

the tube which connects the several chambers of the shell is external (Fig. 84); whereas in *Nautilidæ* it is internal or central to the concavity of

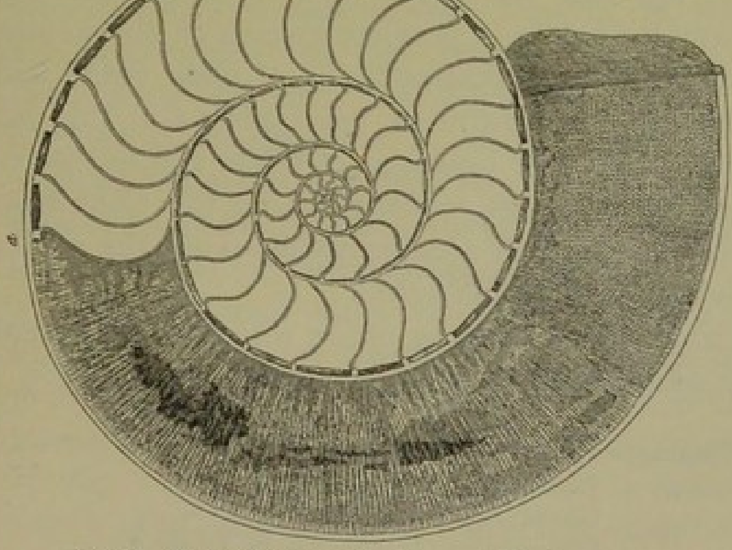


FIG. 84. *Section of Ammonites obtusus.* (After Buckland.)

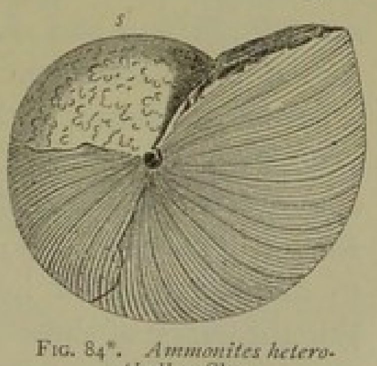


FIG. 84*. *Ammonites heterophyllus*, Sby.

the septa (Fig. 85). 2. The septa or divisions between the chambers are undulated, nearly flat in the centre, and plaited or frilled round the edges, and the sutures, which are seen, when the outer shell is removed, as in Fig. 84*, to be lobed or foliaceous (*s*); while in *Nautilidæ* the septa are merely curved and plain, and the sutures of the shell simple. The relation of these parts one to another, and to the exterior of the shell, is shown in Figures 84, 84*, and 85.

In Morris's Catalogue of 1854, amongst the Jurassic fossils coming under the head 'Incertæ sedis' was *Trigonellites* (*Aptychus*) (see Fig. 128, p. 221). This has since been determined to be the double operculum of Ammonites, it having been found *in situ* closing the aperture of some of the sub-genera; in other sub-genera it is supposed to be wanting.

In the Lias, all the Ammonites have the backs either with an entire keel, or squared and round; those of the latter are the most characteristic, especially the varieties with smooth ribs, such as *A. planicostatus*. The groups with crenated or tuberculated backs, or with backs sharp and compressed, are not found in the Lias.

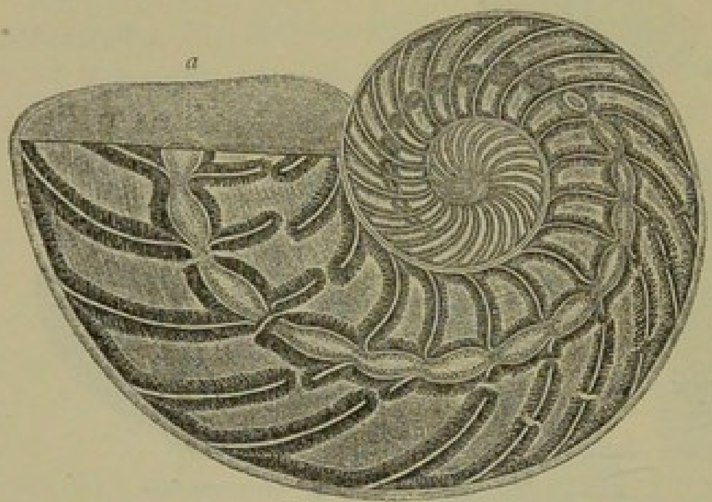


FIG. 85. *Section of Nautilus striatus.* (After Buckland.) *The siphuncle* (*a*) *is distorted by the crystallisation of the calcite.*

Amongst the common species of Ammonites in the Lower Lias are *Ammonites Bucklandi*, *A. obtusus*, *A. raricostatus*; in the Middle Lias or Marlstone *Ammonites margaritatus*, *A. spinatus*; while in the Upper Lias *Ammonites opalinus* and *A. serpentinus* are characteristic.

A close examination of the Lias has shown that it is divisible into a number of zones, each characterised by a peculiar species of Ammonite, —whether the species itself is of rare occurrence, or of wide range and common occurrence, but having its maximum development in the one zone. This rule is so general that the presence of these species serves to define particular horizons both in this country and on the Continent. For the range of these species and of their accompanying fauna the reader should consult the exhaustive work of Dr. Wright[1].

The following are the zones in descending order, with the continental equivalents, and the generic subdivisions to which the species belongs:—

Upper Lias. (Toarcian.)	Ammonites opalinus (*Harpoceras*).
	" Jurensis (*Lytoceras*).
	" bifrons (*Harpoceras*), Pl. VI, fig. 10.
	" heterophyllus (*Phylloceras*), Pl. VI, fig. 9.
	" serpentinus (*Harpoceras*), Pl. VI, fig. 8.

[1] 'Palæontographical Society Monographs,' vols. for 1878–85.

Middle Lias and Marlstone. (Liassian.)	Ammonites spinatus (*Amaltheus*).
	,, capricornus (*Ægoceras*), Pl. VI, fig. 6.
	,, margaritatus (*Amaltheus*).
	,, Henleyi (*Ægoceras*), Pl. VI, fig. 5.
	,, brevispina (*Ægoceras*), Pl. VI, fig. 7.
	,, ibex (*Amaltheus*).
	,, Jamesoni (*Ægoceras*).
Lower Lias. (Sinemurian.)	,, raricostatus (*Arietites*), Pl. VI, fig. 4.
	,, oxynotus (*Amaltheus*), Pl. VI, fig. 3.
	,, obtusus (*Arietites*).
	,, Turneri (*Arietites*).
	,, Bucklandi (*Arietites*).
(Hettangian.)	,, angulatus (*Ægoceras*), Pl. VI, fig. 1.
	,, planorbis (*Ægoceras*), Pl. VI, fig. 2.

Ammonites are now very generally described by palæontologists by the names of the sub-genera given above and others; but for geological purposes I prefer the use of the old generic name. The modern classification is based on the presence or absence of the Aptychus (the operculum),—the length of the body-chamber,—the shape of the mouth-border,—the form of the spiral of the shell, and other structural points, which, although of much palæontological interest, are not so important to the geologist as the preservation of the unity which the retention of the old and wider name ensures.

Several species of Nautilus are also found in the Lias, the commonest forms being *N. truncatus* and *N. striatus* (Fig. 85).

Belemnites, rare in the Trias of Europe where they make their first appearance, swarm in the Lias. Unlike the *Ammonites* and *Nautili*, in which the animal occupied the last chamber of the shell, the shell being external, the Belemnite was a creature like the cuttle-fish, with a peculiar internal shell, or support. Usually it is only this hard calcareous body which is preserved. They are found in vast abundance in most of the Jurassic argillaceous strata.

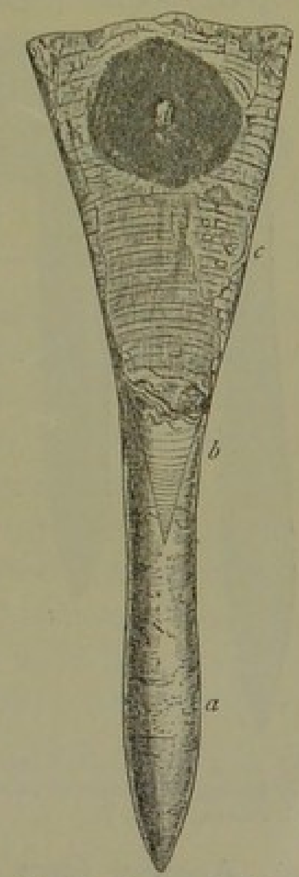


FIG. 86. Section of a Belemnite. (After Buckland.) *a. Guard or Rostrum. b. Phragmacone. c. Conotheca. d. Ink-bag.*

This internal shell of the Belemnite consists mainly of a shaft or pencil of solid fibrous carbonate of lime (the 'guard' or 'rostrum'), which is continued upwards in an attenuated form as the 'pro-ostracum.' In the upper part of the guard is a conical hollow called the 'alveolus.' The more perfect specimens show the presence in the conical cavity or *alveolus*, of a chambered portion called the *phragmacone*; the chambers being separated one from another by concavo-convex shelly partitions or *septa*, which are traversed by a siphuncle along the ventral wall of the phragmacone. This phragmacone was enclosed in a thin shell-wall or *conotheca*, prolonged forward as a horny or shelly plate with the pro-ostracum, and corresponding with part of the 'pen' of the recent *Loligo*. Owing to its extreme delicacy this part is rarely found in the fossil state; when it is so (and there are several such specimens together with their ink-bags in the Oxford Museum) it often shows beautifully iridescent colours.

The body of the Belemnite which enclosed the guard was furnished with lateral fins, and had two long arms and eight shorter tentacles; the former furnished with two rows of suckers, and the latter with numerous horny hooks. It is also known that the animal, like its recent analogue, had an ink-bag, and that its mouth was furnished with horny mandibles. In some specimens even portions of the eyes have been preserved, which, with the head, seem to have been smaller in proportion than amongst other Cephalopoda. (See figure of Belemnoteuthis, p. 218.)

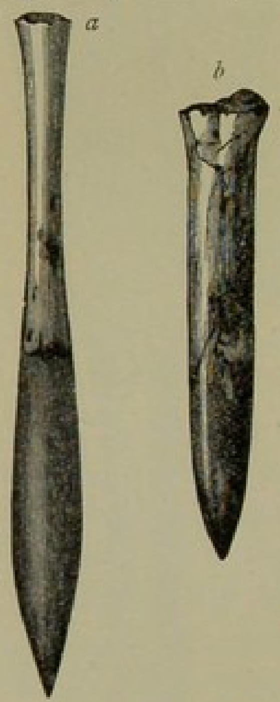


FIG. 87. *a. Belemnites clavatus*, Blainv. *b. Belemnites paxillosus*, Voltz., ⅞.

A great number of the ink-bags have been found in the Lias at Lyme-Regis, a few of them nearly a foot in length, showing that some species of Belemnites attained a very considerable size. The fluid must have been used by the animal to darken the water on the approach of the numerous voracious Saurians which preyed upon it;—just as in the present day the Cuttle-fish of the Mediterranean ejects an inky fluid to save itself from the pursuit of the Tunny and other large fishes. Phillips has described above fifty species of Belemnites from the Lias, of which the most characteristic are *Belemnites clavatus*, *B. elongatus*, *B. breviformis*, *B. longissimus*, and *B. paxillosus*.

The Lias Belemnites belong mainly to the *Acuarii*, or those without lateral furrows, and often channelled at the extreme point, and to the *Clavati*, or those with lateral furrows but no anterior ventral furrow.

Another form of these Dibranchiate Cephalopoda is represented by a single species in the Middle Lias,—the *Xiphotheuthis elongata*, which has its guard, phragmacone, and pro-ostracum relatively, all long and slender, —the last sometimes as much as a foot in length.

THE VERTEBRATA. From the Lias of England alone about 120 species of **Fishes** have been described. They form a peculiar group, very distinct from those we have had occasion to notice in the older rocks. Many of them then had the symmetrical tails which distinguish the Mesozoic from the Palæozoic fishes. A very common species in the Lias of England and the Continent is the *Lepidotus gigas*: another is the *Dapedius Colei.* They are both large, round fishes with hard, shiny, angular scales; there are numerous species of both genera.

Amongst the Sharks, we meet for the first time with several important genera which have a wide range in time, such as *Hybodus* (*H. reticulatus*), characterised by its sharp teeth, with small lateral points (Fig. 88, *b*); together with the *Acrodus* (*A. Anningiæ*) (Fig. 88, *c*), which has crushing teeth, like the Port-Jackson or Cestraciont sharks. The teeth of this genus are curiously formed, having a long rounded surface, covered with fine

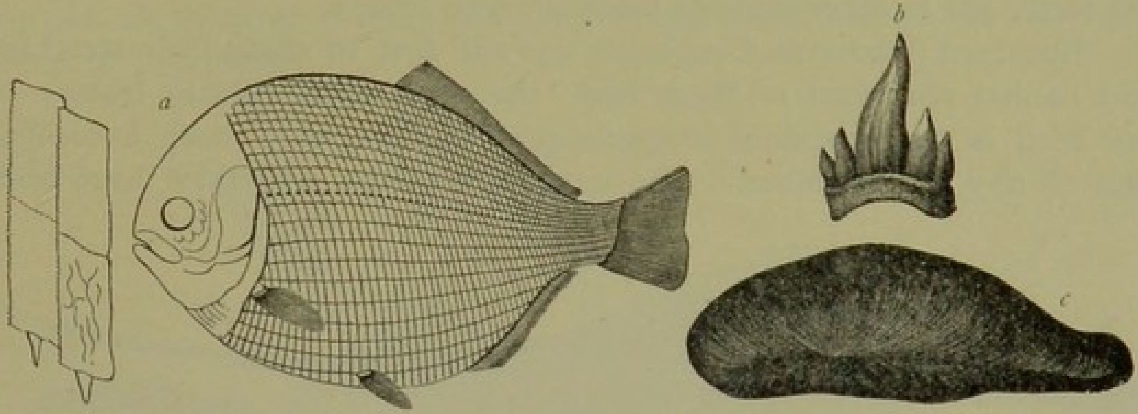


FIG. 88. Fishes of the Lias.
a. Restoration of Dapedius. b. Tooth of Hybodus reticulatus. c. Tooth of Acrodus nobilis.

transverse striæ proceeding from a central longitudinal line. From their general form and black colour they are known as 'fossil leeches' amongst the quarry-men. Both genera are very common in the Lias.

Belonging also to this group of fishes are those peculiar, slightly curved, pointed bodies called *Ichthyodorulites*, mostly fin-spines with small prickles on their hinder or concave margin. They are represented among living fishes by the fins of the Siluridæ, which are for the most part confined to the lakes and rivers of temperate and tropical climates, though a few enter the sea. Some of the fish-spines may have been lateral spikes like those of the Stickleback. These Mesozoic Ichthyodorulites differ from those of Palæozoic age in the circumstance that they 'have their bases modified for articulation with another bone, and were not simply implanted in the flesh.'

Reptiles. Far, however, exceeding in interest all the other fossils of this period are the *Enaliosaurians*, that is to say, marine lizard-like Reptiles. These animals swarmed in the Liassic seas, and the remains of them are abundant at Lyme-Regis, Street, Barrow-on-Soar, and Whitby.

They are amongst the most remarkable of all fossil reptiles, being of generalised types, and uniting apparently very incompatible characters, in having the double concave vertebræ of fishes, the teeth of crocodiles, the bodies of lizards, and the paddles of turtles or cetaceans. They flourished in the Liassic period, but had begun to exist in the Rhætic if not in

Triassic times, and continued to the end of the Cretaceous period. They are therefore essentially Mesozoic reptiles. The most abundant of the *Enaliosaurians* are the *Ichthyosauri* and *Plesiosauri*.

Of the *Ichthyosaurus* or *Fish-lizard* there are no fewer than fifteen described species from the Lias. They vary much in size. There are specimens of *Ichthyosaurus* not more than a foot in length, while specimens of the *Ichthyosaurus platyodon* have a length of more than thirty feet. The head is very large in proportion to the length of the body, partaking of the characters of modern crocodiles in the form and arrangement of the teeth, but in other respects more allied to lizards.

Buckland (who with Conybeare was the first to study their structure and habits) remarked of them that 'the most extraordinary feature of the head is the enormous magnitude of the eye, very much exceeding that of any living animal. The expansion of the jaws must have been

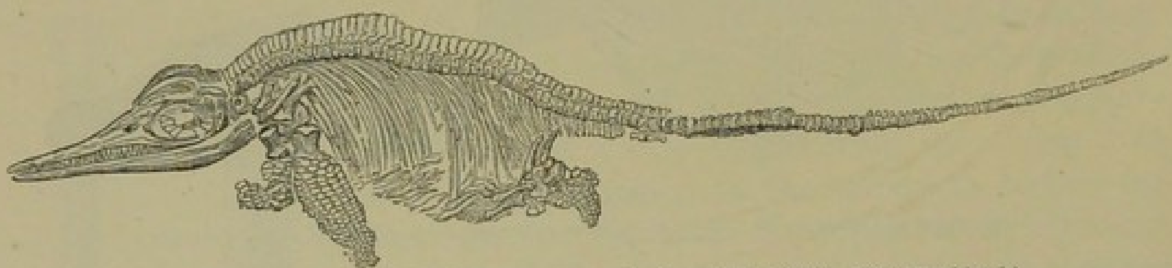


FIG. 89. Specimen of *Ichthyosaurus communis*, from Lyme-Regis. (After Buckland.)

prodigious; their length in the larger species (*Ichthyosaurus platyodon*) sometimes exceeding six feet; the voracity of the animal was doubtless in proportion to its powers of destruction[1].'

The teeth of Ichthyosaurus are conical and much like those of the crocodiles, but considerably more numerous, amounting in some cases to a hundred and eighty; the number varies in each species. They are not enclosed in deep and separate sockets, as the teeth of crocodiles, but are ranged in one long continuous furrow of the maxillary bone. 'As the predaceous habits of the *Ichthyosauri* exposed them, like modern crocodiles, to frequent loss of their teeth, an abundant provision has in each case been made for their continual renewal.'—(Buckland.)

The reptile had a long tail, provided with a large terminal fin-like expansion of the integument. This caused, according to Sir Philip Egerton, the breakage of the tail so often visible in the skeleton, from its falling from the vertical to a flat position after death. The fish-like body was propelled by four paddles. The anterior are very much larger than the posterior paddles, and have a close resemblance to the paddles of turtles. The body was probably covered with a smooth skin, and not with dermal

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1 'Bridgewater Treatise,' vol. i. p. 168.

bones or scales like crocodiles and fishes; but from some impressions upon the shales in which the Enaliosaurian remains at Lyme-Regis are found, it has been conjectured that this skin was like that of some of the sharks, known as shagreen.

Their food consisted chiefly of fishes and cuttle-fish, and in many specimens there may be seen, under the ribs and in the position occupied by the stomach, a mass of the undigested scales and bones of the fishes and innumerable hooklets once borne on the tentacles of the Cephalopods, just described. The cylindrical and somewhat spiral excrements of these reptiles are frequent in the shales (old sea-mud) and are known under the name of Coprolites.

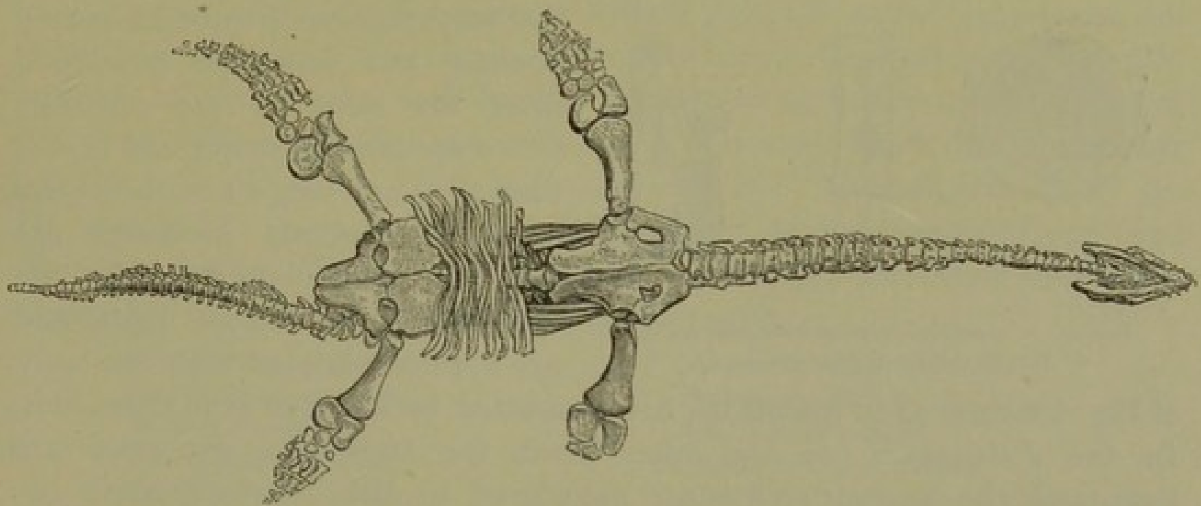

FIG. 90. Specimen of *Plesiosaurus dolichodeirus, ventral surface,* from Lyme-Regis. (After Buckland.)

The other genus of these extinct sea-reptiles, the *Plesiosaurus,* is, as its name implies, still more closely allied to lizards; and its characters are, if anything, still more extraordinary than those of the *Ichthyosaurus.* To the head of a lizard it united the teeth of a crocodile, a neck of great length, as in a swan, a large lacertian body, and the paddles of a whale more highly developed than those of the Ichthyosaurs. In some species the head is very small, but in others it is large and massive, varying from one-ninth to one-half the length of the neck.

Although in the shape of the head, and size and position of the nostrils, the *Plesiosauri* resemble the lizards, they resemble the crocodiles in having teeth lodged in distinct alveoli, with which they do not become ankylosed. The skin was probably smooth, and without scales.

Conybeare observed of the *Plesiosaurus dolichodeirus*: 'May it not therefore be concluded that it swam upon or near the surface, arching back its long neck like the swan, and occasionally darting it down at the fish which happened to float within its reach[1]? It may, perhaps, have

[1] 'Trans. Geol. Soc.' 2nd ser. vol. i. p. 388.

lurked in shoal water along the coast, concealed among the sea-weed, and, raising its nostrils to a level with the surface from a considerable depth, may have found a secure retreat from the assaults of dangerous enemies; while the length and flexibility of its neck may have compensated for the want of strength in its jaws .... by the suddenness and agility of the attack which they enabled it to make on every animal fitted for its prey, which came within its reach.' The large size of its paddles shows that it swam with great speed; it may also have moved on land awkwardly like some seals.

The detached bones of the *Ichthyosaurus* may be distinguished from those of the *Plesiosaurus* by the following characters. In the former the vertebræ are distinctly bi-concave; the only transverse processes they possess are tubercles developed from the sides of the centrum, which are much broader and higher than they are long; and the neural arches or spinous processes are separate, articulating with the vertebræ by a simple joint, and are not consolidated with the body of the vertebræ as in mammals, nor connected by a suture as in crocodiles. In the *Plesiosauri*, on the other hand, the transverse processes are long, and the neural arches are ankylosed to the vertebræ, while the bodies of the vertebræ are either flat or only slightly concave at each end.

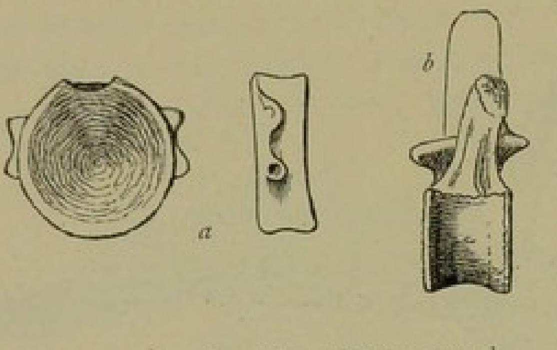

FIG. 91. *a. Dorsal vertebra of Ichthyosaurus*, $\frac{1}{6}$. *b. Dorsal vertebra of Plesiosaurus*, $\frac{1}{6}$.

Again, the bones of the paddle in the *Ichthyosaurus* are much broader and stouter in proportion than they are in the *Plesiosaurus*, and much more numerous; in the latter they are long compared to their breadth; whereas in the *Ichthyosaurus* they are approximately square bones.

Besides these marine Saurians, the flying reptiles, or Pterosaurians, make their first appearance in the Lower Lias, while the great crocodilian reptiles, or the *Teleosaurians*, do not, with one uncertain exception, appear until we reach the Upper Lias. As these are more numerous and common in the Oolitic period, we reserve further notice until treating of those strata. Only two species of each of these orders are known in the Lias.

No Mammalian remains have yet been found, although, as we mentioned before, an early Marsupial form appears in the Trias; and it is shown also, from the occasional presence of ferns and other land-plants, of insects, and of river fishes, that land was not far distant from the Liassic sea of Dorsetshire, Central England, and Yorkshire. The Mendips and Wales may have been islands fringed by the old coast shingle or conglomerates before mentioned; while a larger continental area (now buried beneath the Cretaceous and Tertiary strata) extended eastward from the South of England to Belgium and North-Western Europe.

But if animals were few on the land, the seas teemed with life,—an indispensable condition when we consider the vast quantities of fishes and other marine animals needed for the support of the gigantic Saurians.

Palæontological Character of the Midford Sands. These beds, which we assign with doubt to the Lias, are related palæontologically both to the beds below and above it. They are passage-beds, with many fossils common both to the Lias and the Inferior Oolite. Dr. Wright[1] and Professor Phillips[2] grouped these sands with the Lias, while Professor Buckman[3] claimed them for the Inferior Oolite.

Of the sixty-three species of Mollusca enumerated by Dr. Wright, twenty are common to the Inferior Oolite, and the other forty-three are either Lias species or species peculiar to this zone. Cephalopoda especially abound in the coarse dark-brown calcareo-ferruginous rock, which, at Frocester Hill and other places in the Cotswolds, forms the uppermost bed of this division. This bed — termed the 'Cephalopoda-Bed' by Dr. Wright—is characterised by the presence of *Ammonites* (Lytoceras) *Jurensis*, and *A.* (Harpoceras) *opalinus*. Amongst the other fossils are eleven more species of Ammonites, together with—

Belemnites compressus, *Voltz.*
Chemnitzia lineata, *Sby.*
Modiola plicata, *Sby.*
Hinnites abjectus, *Phil.*
Pecten textorius, *Schloth.*
Myoconcha crassa, *Sby.*
Pholadomya fidicula, *Sby.*
Astarte detrita, *Goldf.*
Nucula Jurensis, *Quenst.*
Rhynchonella cynocephala, *Richard.*

The Liassic period was brought to a close by a change in the physical geography of the district. An elevation of the sea-bed took place, shallow-water and estuarine conditions succeeded. In Gloucestershire the top of the Cephalopoda-bed became exposed, and its surface drilled by boring molluscs, while further north estuarine beds with land plants, which attain their maximum development in Yorkshire, set in.

The foreign equivalents of the Lias will be described at the end of the Jurassic series.

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1 'Quart. Journ. Geol. Soc.' vol. xii. p. 292, and 'Palæntog. Soc. Monographs for 1878-9.
2 'Geology of Oxford,' p. 118.
3 'Quart. Journ. Geol. Soc.' vol. xxxv. p. 736.

CHAPTER XIII.

THE JURASSIC SERIES (*continued*): THE OOLITES.

William Smith. The Lower Oolites. Divisions. Range. Physical Features. The Inferior Oolite. Cheltenham. General Characters. Organic Remains. Plants; Echinoderms; Mollusca. Ammonite-zones. Brachiopod-zones. The Fuller's-Earth. Springs. Fossils. The Great Oolite. The Stonesfield Beds. Abundant Vegetation. Other Organic Remains. Pterodactyles. Marsupial Mammalia. Relations of the Stonesfield and Australian fauna. The other Beds of the Great Oolite. Composition. Structure. Organic Remains. Minchinhampton Fossils. Gigantic Dinosaurs: Megalosaurus. Bradford Clay and Forest-Marble. Limited Range of these Deposits. Organic Remains. Cetiosaurus. The Cornbrash. Organic Remains. Range of Fossils in the Lower Oolites. The Lower Oolites of the Midland Counties, and of Yorkshire. Sea and Land Areas.

The Lias is succeeded by a series of strata of very great interest to the British geologist. It was in these Oolitic rocks that William Smith

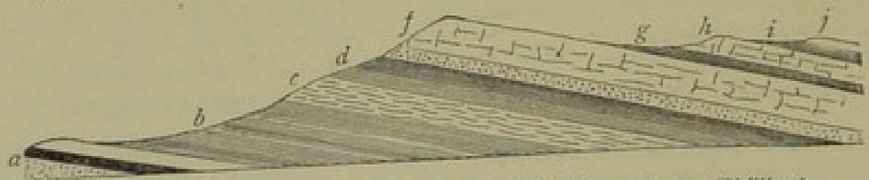

Fig. 92. Section of the Liassic and Lower Oolitic Formations. (Phillips.)
a. Rhætic beds. b. Lower Lias. c. Middle Lias. d. Upper Lias. f. Inferior Oolite. g. Fuller's-Earth. h. Great Oolite. i. Forest-marble. j. Cornbrash.

first demonstrated a definite order of geological succession, and showed that each Formation was characterised by its own peculiar organic remains. Although much has been done amongst both the older and the newer Formations since his time, there has been but little alteration made in the general stratigraphical order which he established for the Jurassic strata. Their local structure and their organic remains are better known, but the relation of the several groups remains without material alteration.

The Lower Oolites. The Oolitic series is divided into a lower, middle, and upper group, the first of which consists, in descending order, of—

Divisions of the Lower Oolite.	5. Cornbrash.
	4. Bradford Clay and Forest-Marble.
	3. Great or Bath Oolite and Stonesfield Beds.
	2. Fuller's-Earth Beds.
	1. Inferior Oolite; Limestones of Lincolnshire; Dogger of Yorkshire.

These constitute a succession of oolitic freestones, and of rubbly and fissile shelly limestones, with subordinate local beds of clay and sandstones. They range uninterruptedly from the Southern to the North-eastern coast of England, and in Scotland fringe the coast of Sutherland and form outliers in Skye. The cliffs near Bridport are composed of oolitic strata; thence they range through Somerset, Gloucestershire, Oxfordshire, Northamptonshire, and Lincolnshire to the coast of Yorkshire, where they constitute the cliffs between Filey and Scarborough.

Throughout this extent the Oolitic strata form an elevated range of hills, generally with a bold escarpment to the west or north-west, overlooking the wide-spreading plains of denudation of Liassic clays and the marls of the New Red. These features are very noticeable to the north of Bath, and are finely marked in the bold range of the Cotswolds above Gloucester and Cheltenham, at Chipping Hampden, and Edgehill. Further north Lincoln Cathedral stands upon the Oolitic escarpment. On the other side the Oolitic strata dip gently to the eastward, forming tracts of bare elevated ground, traversed by deep, pleasant, and well-wooded valleys, with fine springs, pasture-grounds, and many villages.

The abundance of excellent freestone has given to the towns and villages in these districts a picturesque architectural type of their own, and has led to the opening of innumerable quarries, which greatly facilitate the investigations of the geologist.

Unlike the Lias, which maintains uniform characters throughout its range, the Lower Oolites of the south of England present characters so different from those of the north, that it will be better to treat these latter as a separate group, and to describe first the Lower Oolites of Gloucestershire and Oxfordshire.

THE INFERIOR OOLITE[1].

The Inferior Oolite is well seen in the cliffs on either side of Bridport Harbour, and again near Yeovil and Burton in Somerset, where it is largely quarried and very fossiliferous. It is, however, better developed in the neighbourhood of Cheltenham, where it attains a thickness of 264 feet, and consists in descending order of,—1. Trigonia-bed. 2. Gryphæa-bed. 3. Rubbly oolite (Ragstones). 4. Flaggy Freestone. 5. Fimbria-bed. 6. Freestone. 7. Ferruginous Pea-grit.

The bottom bed (7) is composed of a coarse-grained oolite, formed of spheroidal grains about the size of peas, imbedded in a calcareous and ferruginous matrix, whence its name '*Pisolite*' or 'Pea-grit.' It is here 38 feet thick. Above is a finer-grained oolite (6), ferruginous at base, called 'Roe-stone,' from its resemblance to the roe of fishes, passing up into a compact light-coloured oolitic freestone, composed in large part

[1] 'Oolite' itself signifies 'roe-stone,' and is a generic term applied to those rocks which consist of very small round calcareous grains imbedded in a calcareous cement.

of comminuted shells, with a small-grained oolitic structure, much used as a building-stone, being soft, easily worked and sawn in the quarry, while it hardens by exposure and is very durable. Great part of Cheltenham is built of this stone. This and the roe-stone are together 110 feet thick. The grains of these oolitic beds were formed around shell-banks and coral-reefs. Comminuted fragments of organic débris and of sand formed centres round which was deposited the excess of carbonate of lime held in solution in such waters, the rounded shape being due to the constant motion kept up by wave and current action. Ultimately these were cemented together by a further deposition of carbonate of lime (Fig. 93. See also Vol. I, p. 240).

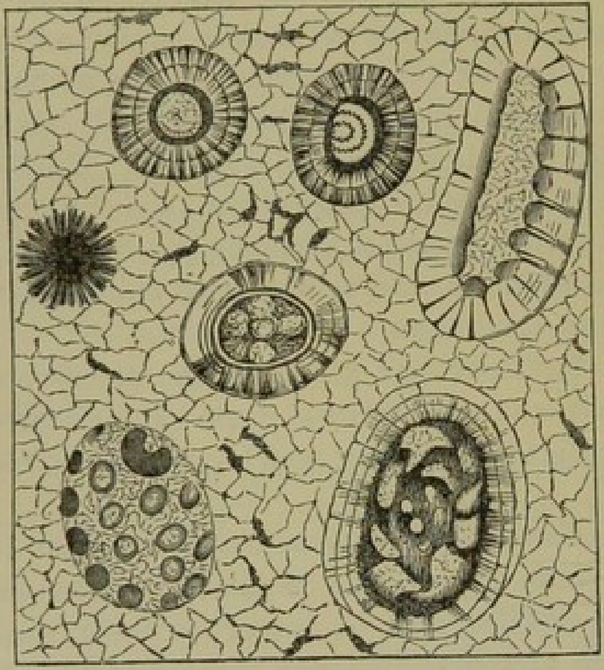

FIG. 93. *Magnified grains of Oolite* (Bath) *collected round various objects, in a paste of calcite* (Phillips).

A similar result is obtained in boilers, where the grains detached from the calcareous crust sometimes serve as nuclei for a further deposition of carbonate of lime, while the motion kept up by boiling gives a spherical form to the little bodies. It is the same in the stream of the Carlsbad and other waters.

The oolitic beds are succeeded by seventeen feet of cream-coloured marls (5), with *Terebratula fimbria* and *Ammonites Murchisoni* (Pl. VII, fig. 1), overlying which are flaggy freestones (4), with *Ammonites Humphriesianus* (Pl. VII, fig. 3), 26 feet thick. The Ragstones (3) consist of thirty-eight feet of sands, sandstones, and rubbly oolites, only fit for road-purposes and walls. The upper beds are characterised (2) by the abundance of Gryphæa (*G. sublobа*) and (1) of Trigonia (*T. costata*).

As they range northwards, the beds of the Inferior Oolite undergo considerable change; we shall consider these northern types separately at the end of this chapter.

Organic Remains. The cliffs at Bridport and the quarries around Yeovil are very fossiliferous. Dundry Hill, near Bristol, has long been a classical locality for Inferior Oolite fossils; but it is in the neighbourhood of Bath and Cheltenham that the several zones are best marked and known[1].

[1] The student may study with advantage the various memoirs on the Somerset and Gloucestershire districts by Mr. Lonsdale, Sir R. Murchison, Professor Buckman, Professor Hull, Mr. Lycett, Professor Morris, and Dr. Wright; and for the Oxfordshire district, the papers of Professor Phillips, Mr. Beesley, and Mr. A. E. Walford.

Plants. In the South of England plant remains are rare in these strata, and generally confined to fragments of coniferous wood; but a few specimens have been found of considerable interest, such as the cone of a tree (*Araucarites sphærocarpus*, Carr.) from Burton, related to the Araucarian pines so abundant in Australia and some of the adjacent islands; also the fruit of a tree (*Podocarya*) allied to the *Pandaneæ* or Screw-pines of the Indian Archipelago and the islands of the Pacific, found in the neighbourhood of Charmouth. This fruit, a fine specimen of which is in the Oxford University Museum, is about the size of an orange.

The **Corals** are of much interest. They are chiefly confined to the Lower Pisolitic beds, and form in places reef-like masses. Some of the genera, such as *Isastræa*, *Montlivaltia*, *Latimæandrina*, and others, had already appeared in the Lias, whilst some, such as the *Thamnastræa* and *Stylina*, now appear for the first time.

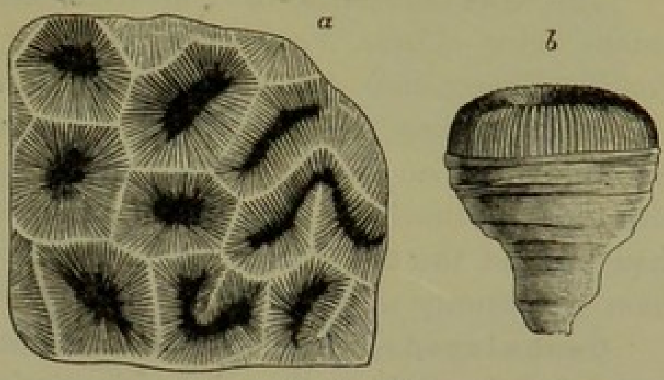

FIG. 94. Inferior-Oolite Corals.
a. Latomæandrea Flemingi, M. Edw. *b. Montlivaltia trochoides*, M. Edw.

The **Echinodermata** are extremely abundant, especially Echinoidea of the genera *Clypeus*, *Echinobrissus*, and *Pygaster*, which also now make their first appearance. On the other hand, Crinoids, which were so abundant in the Lias, are scarce; and the *Asteroidea*, or Star-fishes, are almost unknown, as are also Annelides and Crustacea. The following are some of the characteristic species of Echinoidea:—

Clypeus Plotii, *Klein*. Pl. VIII, fig. 6.
Echinobrissus clunicularis, *Lloyd*. Pl. VIII, fig. 2.
Hyboclypus gibberulus, *Ag*. Pl. VIII. fig. 4.
Cidaris Fowleri, *Wright*.
Polycyphus Deslongchampsii, *Wr*. Pl. VIII, fig. 7.
Pseudodiadema depressum, *Ag*.
Pedina Smithii, *Wright*.
Stomechinus perlatus, *Desor*.

The **Brachiopoda** are reduced to the genera *Rhynchonella* and *Terebratula*, with a few species of *Discina*, *Thecidium*, and of *Lingula*. Of the two former the number of species is however considerable (above seventy), while the number of individuals is sometimes enormous, as in the case of the Marl-bed, in which the characteristic *Terebratula fimbria* occurs in thousands, and gives its name to the bed. Amongst other common forms of the Inferior

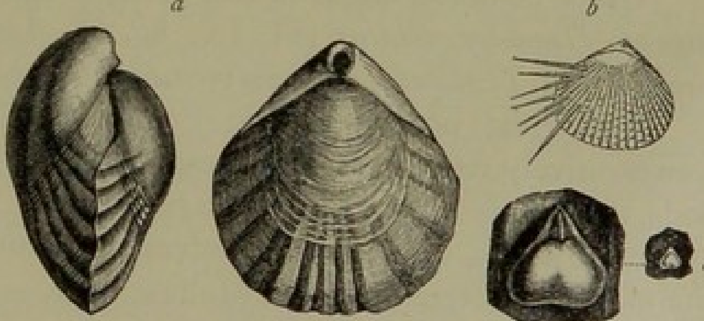

FIG. 95. Inferior-Oolite Brachiopoda, etc.
a. Terebratula fimbria, Sby. *b. Rhynchonella spinosa*, Schloth.
c. Thecidium triangulare, D'Orb.

Oolite are *Terebratula plicata*, *T. Phillipsii*, *T. submaxillata*, *T. simplex*, and *Rhynchonella decorata*; *Rhynchonella spinosa* is characteristic of the upper beds of the Inferior Oolite.

Among the **Lamellibranchiates** the most characteristic are species of *Astarte*, *Gresslya*, *Cardium*, *Cucullæa*, *Modiola*, *Myacites*, and *Pholadomya*. But the genus of special interest is *Trigonia*, which, rare in the preceding formations, has now no fewer than thirty-four species. This shell, which ranges through all the Mesozoic formations, is not found in Tertiary strata, nor does it exist in any European seas; but one species still survives in the seas of Australia.

The **Gasteropoda**, or Univalves, are less numerous, the principal genera being *Alaria*, *Nerinæa*, *Pleurotomaria*, *Trochus*, and *Natica*; while *Patella*, *Emarginula* and *Fissurella* make their first appearance.

In examining the list of the Mollusca, it is well to note that, while the Monomyarian bivalves show an almost complete generic agreement with those of the Lias, the Dimyarian group is considerably extended and changed, and the two characteristic Liassic genera *Cardinia* and *Hippopodium* are entirely wanting.

Cephalopods, which so abound in the Lias, are comparatively scarce in the Inferior Oolite; though a few species of Ammonites are, as in the Lias, common and characteristic of certain zones.

The remains of **Fishes** are still scarcer; and **Reptiles** are equally so. They are confined chiefly to the teeth of *Acrodus* and the few remains of a large Enaliosaurian.

The fossils are distributed very irregularly. The Pisolitic bed at the base of the Inferior Oolite is especially rich in *Echinoidea*, which are described by Dr. Wright in the volumes of the Palæontographical Society. This bed also contains in its upper part a variety of corals, which rarely range higher, the most common species being *Thecosmilia gregaria*, *Thamnastræa Terquemii*, *Montlivaltia De-la-Bechi*, and *Latimæandrea Flemingi*.

Other common shells of this division are *Trochotoma carinata*, *Patella rugosa*, *Hinnites velatus* (Pl. IX, fig. 6), *Avicula complicata*, *Terebratula simplex* and *T. plicata*, and *Ammonites Murchisonæ* (Pl. VII, fig. 1).

The great bed of Oolitic Freestone which next succeeds, contains comparatively few fossils, and these are chiefly in fragments. In the upper beds the fossils are again better preserved. We here find a large number of bivalve shells, with fewer univalves, and some Echinodermata. Amongst the most characteristic of the Mollusca are,—

Ostrea Marshii, *Sby*. Fig. 96, *d*.
Opis trigonalis, *Sby*. Pl. IX, fig. 1.
Lima proboscidea, *Sby*. Fig. 96, *c*.
Ceromya concentrica, *Sby*. Pl. IX, fig. 2.
Trigonia costata, *Park*. Fig. 96, *e*.
Gresslya abducta, *Phil*. Pl. IX, fig. 5.
Phaladomya lyrata, *Sby*
Trochotoma carinata, *Lycett*.

Tancredia donaciformis, *Lycett*. Pl. IX. fig. 3.
Chemnitzia procera, *Desh.*
Delphinula furcata, *Goldf.*
Nerita lineata, *Morr. & Lyc.*
Pileolus plicatus, *Sby.* Pl. IX, fig. 13.
Emarginula scalaris, *Sby.*
Ammonites Humphriesianus, *Sby.* Pl. VII, fig. 3.
,, Parkinsoni, *Sby.* Pl. VII, fig. 5.

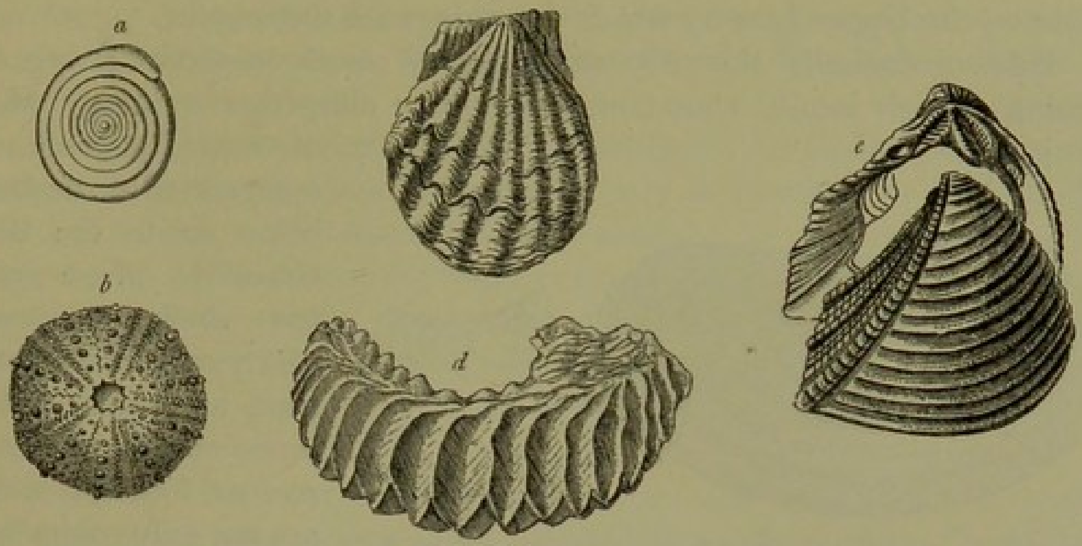

FIG. 96. Other Fossils of the Inferior Oolite.
a. Spirillina Helvetica, Küb. and Zw. × 25. *b. Pedina Smithii*, Wright. *c. Lima proboscidea*, Sby. *d. Ostrea Marshii*, Sby. *e. Trigonia costata*, Park.

Dr. Wright divided the Inferior Oolite into three zones, each characterised by its peculiar Ammonite; the lower and larger being the zone of the *Ammonites Murchisonæ*; the next, or middle, that of *A. Humphriesianus*; while the thin zone at top is that of *A. Parkinsoni.*

Mr. Lycett, on the other hand, divides the Inferior Oolite into two divisions; the lower being characterised by the presence of *Terebratula fimbria*, and the upper by *Rhynchonella spinosa*, a fossil which has a wide geographical distribution both in England and on the Continent.

The Fuller's-Earth is a local argillaceous deposit separating the Inferior from the Great Oolite. It consists of beds of brown and blue clays with irregular beds of nodular limestones, and is of restricted range. In Dorsetshire it forms a division of some importance, being about 400 feet thick; in the neighbourhood of Bath it is 150 feet; at Cheltenham it is still further reduced, and, becoming gradually thinner as it ranges eastward, finally disappears between Burford and Oxford. Unimportant as this division is in the Cotteswolds, its economic value both there and around Bath is considerable, for it holds up the water in the overlying Great Oolite and forms a water-bearing zone amongst those hills, where otherwise many tracts would be dry and arid. As it is, the clays of the Lias and of the Fuller's-Earth sustain large underground stores of water, the source of some of the finest springs in the country,—such as, on the eastern slopes of the Cotteswolds,—the Seven Springs near Northleach, and the great springs of Bibury and Ablington near Fairford, of Ampney near Cirencester, of Boxwell near Cricklade, of Bourton, and many others, all due to the presence of the Fuller's-Earth clays under the permeable beds of the Great Oolite; while the fine springs of Syreford and the Seven Wells, on the summits of the Cotteswolds above Cheltenham, and of the Thames Head near Cirencester, originate in the overlie of thick beds of permeable Inferior Oolite on the Upper Lias by which the springs are thrown out.

Palæontologically this deposit is not of much importance, organic remains, though locally abundant, being often altogether wanting. Most of them also are common, either to the beds below or to the beds above it. There are a few shells, however, which are characteristic, such as small *Ostrea acuminata* and the *Homomya Vezelayi*, which are not only common in the Cotteswolds, but are also abundant in the equivalent beds in France and Switzerland. Other Lamellibranchs are *Ostrea rugulosa*, *Myacites calceiformis*, *Ceromya plicata*, *Avicula echinata*, *Pecten vagans*, and *Arca lata*. A variety of *Terebratula perovalis*, and *Rhynchonella concinna*, are the prevailing Brachiopods[1]. There is a singular absence of fishes and reptiles; and the invertebrate fauna is much impoverished, amounting to only 110 species. There is, however, in places, a remarkable abundance of Ostracoda and Foraminifera.

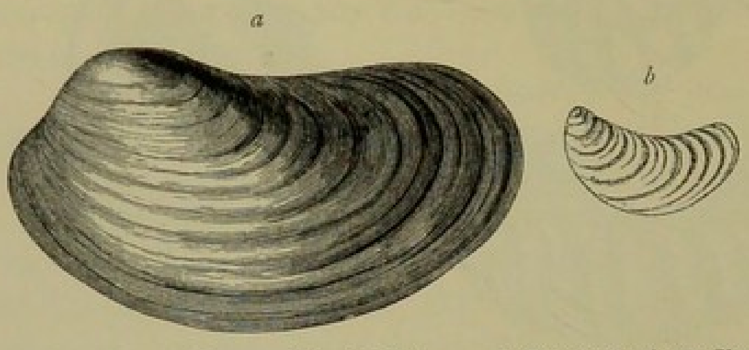

FIG. 96*. *a. Homomya Vezelayi*, Laj. *b. Ostrea acuminata*, Sby.

THE GREAT OR BATH OOLITE.

The Stonesfield Beds. The lowest division of the Bath Oolite is that known as the Stonesfield beds or 'Stonesfield Slate.' This also is a very local deposit, being restricted to Gloucestershire and Oxfordshire. It is well marked around Eyeford near Stow-on-the-Wold, but is better known and richer in organic remains at Stonesfield near Woodstock, where it has been worked for ages as a roofing-stone.

Although termed 'slate,' it is not by any means a slate, in the ordinary sense, but a very fissile and false-bedded shelly oolitic limestone, forming large tabular masses, which split (by frost) into thin slabs, of a light yellowish grey colour, formerly much in use at Oxford as a substantial, but heavy, roofing-stone. Fossils occur in extraordinary abundance. Scarcely a fragment of the stone can be taken up that is not covered with impressions of *Trigonia*, *Gervillia*, *Pecten*, *Rhynchonella*, *Eulima*, and other

[1] Lycett, 'The Cotteswold Hills,' p. 89.

shells, and fish-scales. Any number of these may be obtained in the large rubbish heaps at the mouth of the pits, and of the workmen.

The flaggy bed is only from 5 to 10 feet thick, and to reach it 50 or 60 feet of superincumbent Oolitic strata have to be traversed. Instead therefore of being worked in open quarries, the so-called 'slate' is obtained by sinking shafts down to the workable stratum, in which galleries are then driven as in coal-pits.

Stonesfield Fossils. Although many of the fossils of this special bed are identical with those of the upper part of the Bath or Great Oolite, still they furnish, as Professor Phillips[1] remarks, so definite 'and instructive a series of life-forms, and were accumulated under so much of local peculiarity, as to require a separate enumeration.' They indicate land-conditions that are wanting in the beds of the same age in other districts, and afford a good general type both of the Fauna and Flora of the Great-Oolite epoch.

Plants. Professor Phillips enumerates from these beds nine species of Ferns, one Endogenous or Monocotyledonous plant, eight Cycads, five

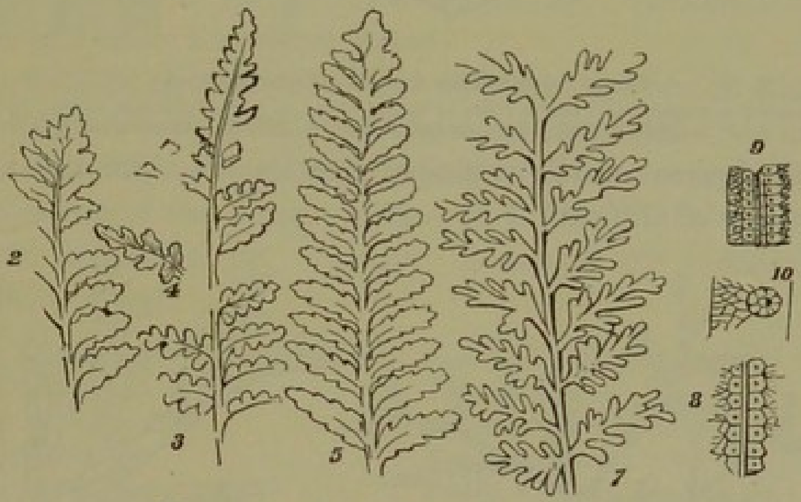

FIG. 97. Great-Oolite Ferns. (From Phillips.)
2. *Pecopteris approximata*, Phil. 3, 4. *Sphænopteris plumosa*, Phil. 5. *Pecopteris incisor*, Phil. 7. *Sphænopteris cysteoïdes*, Lindl. 8, 9, 10. *Tæniopteris angustata*, Phil.

Conifers, and four fruits or seeds. The Ferns are abundant, the predominant genera are *Sphenopteris* and *Pecopteris*, but they are not well characterised.

The Cycads are mostly of the same genera as those occurring elsewhere in the Lower Oolites, but many of the species are different; amongst the coniferæ one is allied to the Araucarian pines. The luxuriance of this vegetation is shown by the circumstance that some of the leaves of the Palæozamia are a foot in length.

[1] 'Geology of Oxford,' p. 167. The student should consult this work for an excellent description of the geology and full particulars of the fossils of this and adjacent Jurassic districts.

Coniferæ are as abundant as the Cycadaceæ, but, as with the other plants, the impressions, owing to the coarseness of the stone, want definition.

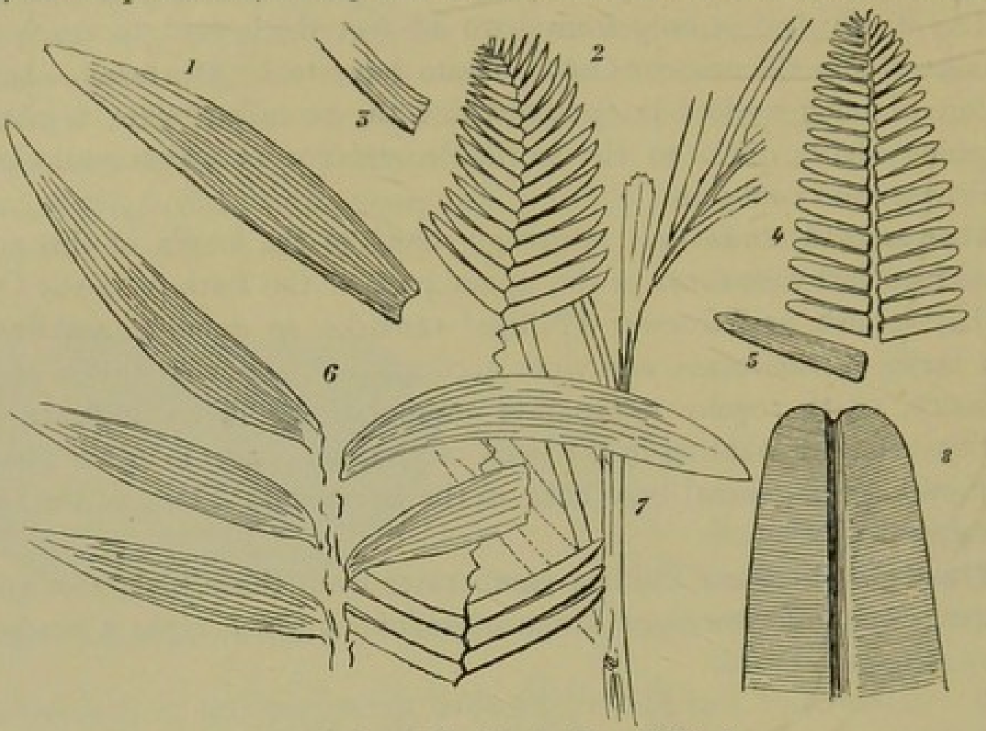

FIG. 98. Great-Oolite Cycads. (From Phillips.)
1. *Leaf of Palæozamia megaphylla*: leaves often 12 inches long. 2, 3. *P. pectinata*, Stern. 4, 5. *P. taxina*, L. and H. 6. *P. longifolia*, Phil. 7. *A ramose plant*. 8. *Tæniopteris scitamineæ-folia*, Stern.

The following figures of the principal species are, like the above, from Phillips' 'Geology of Oxford.'

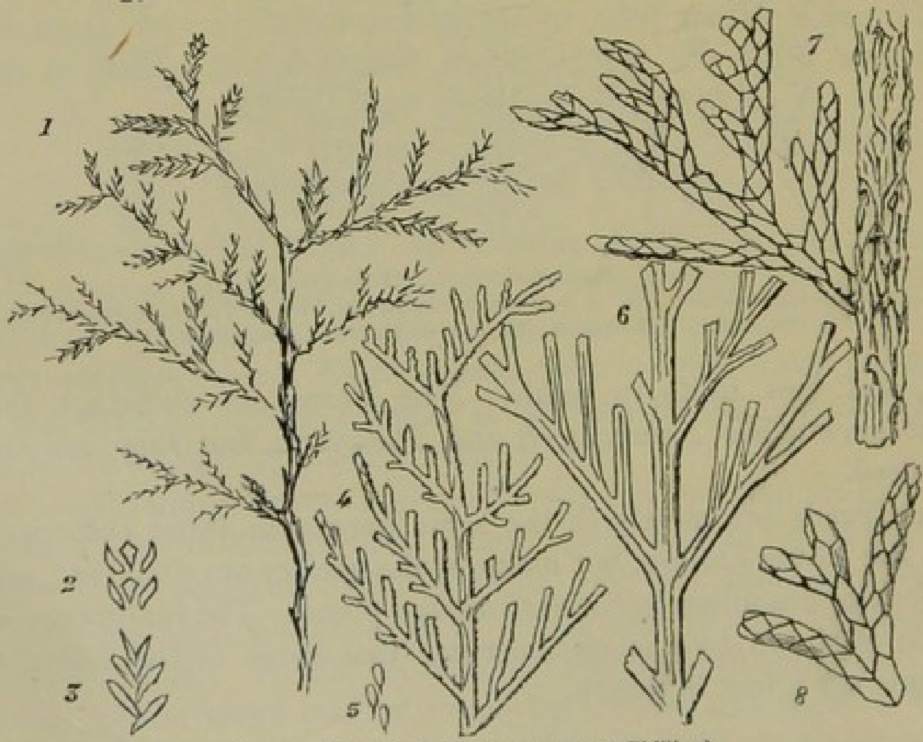

FIG. 99. Great-Oolite Coniferæ. (From Phillips.)
1, 2, 3. *Thuytes articulatus*, Stern. 4, 5. *T. expansus*? Stern. 6. *Taxites podocarpioides*, Brong. 7, 8. *T. divaricatus*, Stern.

Of the fossil seeds found in the Stonesfield beds, some are supposed to belong to Thuytes and others to cycadaceous plants, to one of which the fine specimen of *Bucklandia squamosa*, Brong., in the Oxford Museum, is referred.

Corals are rather scarce, and there are not many **Echinodermata**, although one species, the *Hemicidaris Stokesii*, is not uncommon.

Although **Insects** made their appearance in the Devonian period, their remains continue scarce up to the time of the Stonesfield beds, when, judging from the many fragmentary remains, they must have been very numerous. There were beetles (*Prionus*) approaching nearly to the recent *Buprestis*, a genus of Coleopterous insects, now chiefly frequenting the woods and forests of hot climates. Others again are flying insects belonging to the order of the common dragon-fly. Hundreds of the harder sheath-wings of beetles have been found.

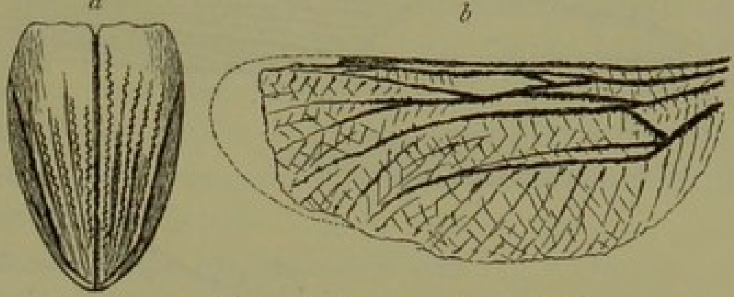

FIG. 100. Insects of the Stonesfield beds (Phillips).
a. Wing of a Buprestidium. b. Wing of Libellula Westwoodii.

Phillips records no **Polyzoa**, and only four species of **Brachiopoda**, of which the *Rhynchonella obsoleta* is the most common.

Mollusca are numerous, and mostly of the same species as those of the upper divisions of the Great Oolite and Forest Marble, some of which will be found figured at pp. 204–205. Amongst the more characteristic may be mentioned—

Ostrea Sowerbyi, *Morr. & Lyc.*
Gervillia acuta, *Sby.*
Avicula Munsteri, *Goldf.*
Lima punctata, *Sby.*
Pecten vagans, *Sby.*
Cardium acutangulum, *Phil.*
Pholadomya acuticosta, *Sby.*
Neæra Ibbetsoni, *Morr.*
Trigonia impressa, *Sby.*
Eulima communis, *Morr. & Lyc.*
Nerita costulata, *Desh.*
Patella Roemeri, *Morr. & Lyc.*
Ammonites Waterhousii, *M. & L.* (Pl. VII, fig. 7.)
Nautilus Baberi, *Morr. & Lyc.*

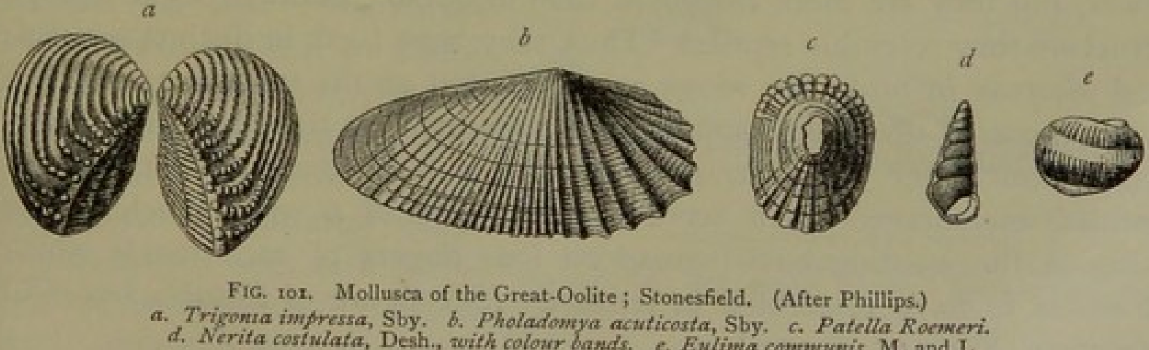

FIG. 101. Mollusca of the Great-Oolite; Stonesfield. (After Phillips.)
a. Trigonia impressa, Sby. *b. Pholadomya acuticosta*, Sby. *c. Patella Roemeri. d. Nerita costulata*, Desh., *with colour bands. e. Eulima communis*, M. and L.

A number of **Fish** remains are found, but generally in a very fragmentary condition. The jaws, scales, vertebræ, and bones of some of the small Lepidosteoid fishes are common, so also are the palatal nail-headed teeth of Pycnodonts, together with the larger, square or lozenge-shaped crushing teeth of some of the Placoid fishes. The dorsal spines of *Hybodus* and of some Cestraciont Sharks are likewise of frequent occurrence. The following are figures of some of the more common species.

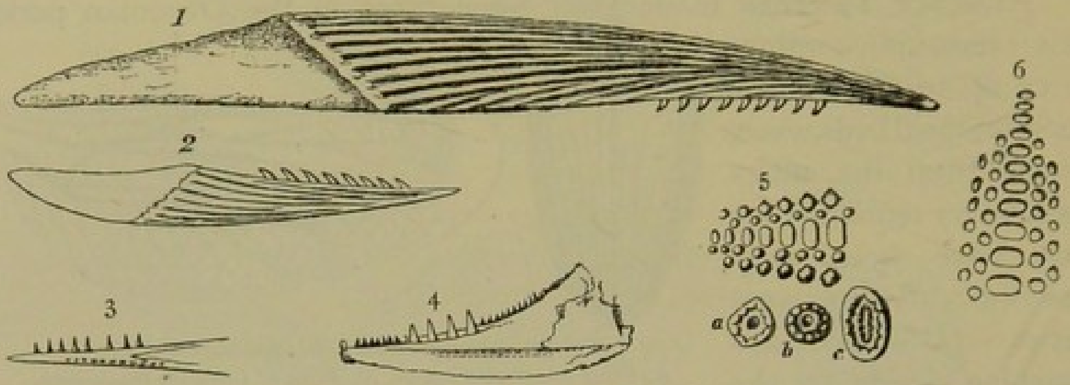

FIG. 102. Fishes of the Great Oolite. (Phillips.)
1. *Spine of Hybodus, dorsalis* Ag. 2. *H. apicalis*, Ag. 3. *Jaw of Belonostomus leptosteus*, Ag. 4. *Pholidophorus minor*? Ag. 5. *Palatal teeth of Gyrodus trigonus*, Ag. (*a*, *b*, *c* enlarged figures of the three rows). 6. *Pycnodus rugulosus*, Ag.

Of **Reptiles** very few marine Saurians are found, and those only represented by detached scattered bones; but the Crocodilian *Teleosaurus* occurs more frequently, together with the remarkable Dinosaur, the *Megalosaurus Bucklandi*. Of these reptiles further mention will be made in describing the Great Oolite.

The remains of the curious flying reptile, the *Rhamphorhynchus Bucklandi*, are not at all uncommon. This genus belongs to the order of *Pterosauria*, that is to say, winged Saurians (*Ornithosauria* of Seeley), of an extinct order of reptiles, which made their first appearance in the Liassic period, and continued to exist all through the Mesozoic period, ending only with the Chalk. Their bones are light and hollow. In this, and in the shape of the skull, they bear some likeness to birds, as they also do in the strength of their cervical vertebræ; but the number of vertebræ is fewer, and they are more elongated than in birds. In other points of their structure they resemble reptiles. Thus, they have teeth in distinct sockets; and whereas in birds the wings are supported on the inner fingers of the hand, those of the Pterosaurians were supported on the outer finger only. This outer finger was enormously elongated, and connected with an expanded membrane, which served the purpose of a wing, much as the wing of the existing bats (spread on four fingers of each hand), which it seems to have resembled in texture. (See figure of Marsh's beautiful specimen, Fig. 131, p. 253.)

The only existing reptile which possesses any powers of flight is the little *Draco volans*; but this is only able to take extended leaps from tree to tree, in a way that cannot properly be called flying. That Pterodactyles, on the other hand, possessed powers of genuine flight is indicated by the presence of a median keel on the sternum, and by many other points of structure. A considerable number of fossil species are known, varying in size from that of a snipe to others which had an expanse of twenty feet from tip to tip of the wings.

The Stonesfield species differs from ordinary Pterodactyles in having no teeth in the anterior portion of the jaw; and it has therefore been referred to a new genus, *Rhamphorhynchus*, so termed from having the front of the jaws ending in a beak like that of a bird. It differed also probably from the ordinary Pterodactyles in the nature of its food, which Professor Phillips suggested may have consisted mainly, like that of the Cormorant and other water-birds, of fishes.

We know of no true **Birds** in the Stonesfield strata.

But the most interesting of all the remains of the Stonesfield beds are the small jaws referred to **Marsupial quadrupeds**. The first of these were discovered about sixty years ago, and were long supposed to be the oldest of the Mammalia. Later discoveries have, however, as before mentioned, carried back the existence of similar small Mammals to the period of the Uppermost Trias. With that exception, these Stonesfield remains still retain their primogenial position. These small warm-blooded creatures would scarcely attract notice in the midst of their huge reptilian contemporaries; but, while these great and powerful reptiles have gradually diminished in numbers, or disappeared, their dwarfed representatives now occupying a very restricted place, the then insignificant Mammalia have, on the contrary, gradually increased in classes, numbers, variety, and power, until they now form the predominant denizens of our plains and forests.

Four species, belonging to three genera, are known from the Stonesfield beds. 1. The *Amphitherium*, of which there are two species; the teeth are such as are suited to a vermivorous or insectivorous animal. 2. The *Phascolotherium*, which is allied to *Didelphys*, or the Opossum of America. And 3. The *Stereognathus*, which Professor Owen surmises may have been a placental quadruped, hoofed and with herbivorous habits of life. These early mammals were of very small size, varying from that of a rat to that of a rabbit; and, with the one exception, they all had marsupial characters like the Kangaroos and other animals of Australia.

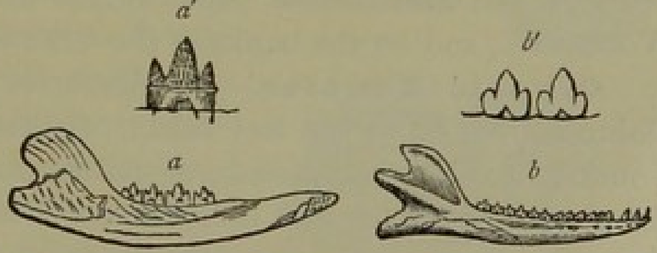

FIG. 103. Mammalia of the Stonesfield beds. (Phillips: from specimens in the Oxford Museum.)
a. Phascolotherium Bucklandi, Broderip. *b. Amphitherium Prevostii*, Cuv. The jaws are of natural size; the teeth, *a'*, *b'*, enlarged.

With the occurrence of those small Marsupials, it is interesting to note how, in many other respects, the life and plant conditions then prevailing in the British area are represented by those which now obtain in Australia. Thus, the Cycads and the Araucarian pine were then in this area, as they now are in Australia, common forms. It is also in the seas of that continent that the peculiar Cestraciont Shark of Port Jackson, with its crushing teeth and fin-spines, at present abounds; while the common shell of the Oolitic period, the *Trigonia*, finds its last and only living representative on the same Australian shores. The *Ceratodus*[1], though it still survives from Triassic times, has also now no existing representative except the Barramunda of the Queensland rivers.

The other beds of the Great Oolite. The Stonesfield beds are, however, only of local occurrence. The main body of the Great Oolite is more massive and more persistent. It caps the hills around Bath, where it overlies the Inferior Oolite and Lias, which crop out on the slopes and in the valleys below. It also ranges over the Cotteswold Hills. Owing to its value as a building-stone, it is largely quarried.

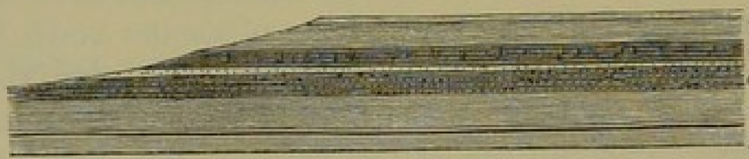

FIG. 104. Section of Round Hill, Landsdown, near Bath (reduced from the Geol. Survey).
a. Great Oolite. b. Fuller's-Earth. c. Inferior Oolite. d. Marlstone. e. Lias. f. New Red Sandstone.

It consists of shelly freestones, thin-bedded rubbly oolites, with fine soft yellowish beds of thick oolite, which hardens on exposure, together with subordinate beds of impure shelly limestone. The middle and lower beds yield the best building-stones. It is extensively used in Bath[2]. The quarries at Corsham also supply large quantities for London and elsewhere. It is again well exposed in quarries between Burford and Witney; and also on the banks of the Evenlode between Charlbury and Woodstock, and on the banks of the Cherwell at Enslow Bridge.

Organic Remains. In Somerset and Gloucestershire the Bath Oolite is from 80 to 120 feet thick. It thence passes through the Midland Counties to Northamptonshire, undergoing in its northern range great changes of character and dimensions. These will be described further on. We will at present consider only the more southern type.

It is in the Cotteswold Hills that the organic remains are very numerous and well preserved in the Great Oolite. The old quarries on Minchinhampton Common, not far from Stroud, are particularly rich

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[1] Quoted by Phillips from Stonesfield, but the specimen has been lost.

[2] It was used in the eleventh century in the construction of the Glastonbury Abbey-Church, and subsequently of Wells Cathedral and Bath Abbey-Church.

in fossils. The Formation is there divisible into five fossiliferous zones, which furnished Professor Morris and Mr. Lycett with 336 species of Mollusca [1]. The upper division there is termed 'planking,' in consequence of the great width of the beds. The next is a soft oolite; the third a shelly oolite; the fourth is termed 'weather-stones;' and the last the 'basement-bed.' Mr. Lycett [2] remarks that 'the profusion of shells in certain layers towards the base of the soft oolite, and occasionally in the "planking," is excessive; the surfaces of some thin beds of the latter are strewed over with small spiral univalves of the genera *Nerinæa* and *Cerithium*; other univalve genera are *Nerita*, *Patella*, *Pileolus*, *Ceritella*, *Cylindrites*, *Trochus*, *Turbo*, *Trochotoma*, *Natica*, *etc.*; the bivalves most abundant are species of *Tancredia*, *Gervillia*, *Sphæra*, *Pecten*, *Lima*, *Arca*, *Limopsis*, *Ostrea*, etc. With these are found spines and plates of Echinoderms, fragments of corals, crabs' claws, fishes' palates, fragments of wood,' etc. Throughout the section generally, however, bivalve shells constitute by very much the greater portion of the shelly mass, although in number of species they do not materially predominate over the univalves. Cephalopoda are rare, and consist chiefly of two species of Belemnites, with a few Ammonites usually broken; but two species of Nautilus, with stronger shells, have more frequently escaped injury. This paucity of Cephalopoda throughout the Great Oolite of the Cotteswolds appears to be a feature which obtains throughout the formation generally, both in England and on the Continent, a special bed of Ammonites having never been discovered in it.

Plants, so common in the Stonesfield beds, are scarce in the other divisions of the Great Oolite.

Corals are rarer than in the Inferior Oolite. There is, however, one bed near Cirencester where they form an entire bank, although only from one to three feet thick,—the most frequently occurring species being *Cladophyllia Babeana*, *Cyathophora Pratti*, *Isastræa explanulata*, *Montlivaltia trochoides*, and *Stylina solida*. *Anabacia orbulites* is common to both the Inferior and the Great Oolite.

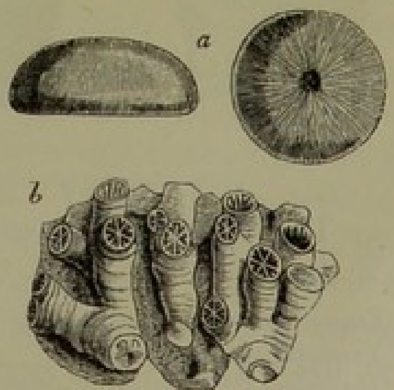

FIG. 105. *a. Anabacia orbulites*, Lam. *b. Cladophyllia Babeana*, D'Orb.

Nor are *Echinodermata* so abundant as either in the stage below or in the stage above: the characteristic species are *Echinobrissus Woodwardi* and *Clypeus Mulleri*.

Of the *Crustacea* a few fragmentary remains are occasionally found; the most frequently occurring species being *Glyphea rostrata*.

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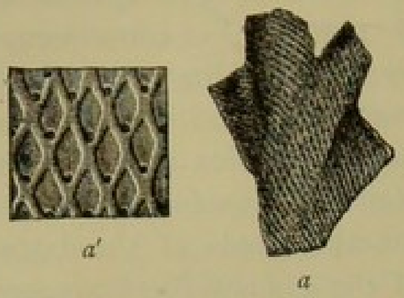
[1] Palæontographical Society's Monographs for 1850 and 1853.
[2] 'The Cotteswold Hills,' p. 94.

Polyzoa are tolerably abundant in the Great Oolite near Bath, especially species of *Diastopora*, but they are found in greater variety in the Forest Marble and Cornbrash. It is, however, in the Bathonian of Normandy that they most abound, sometimes forming entire beds (Calcaire à polypiers). Annexed are some of the most characteristic forms.



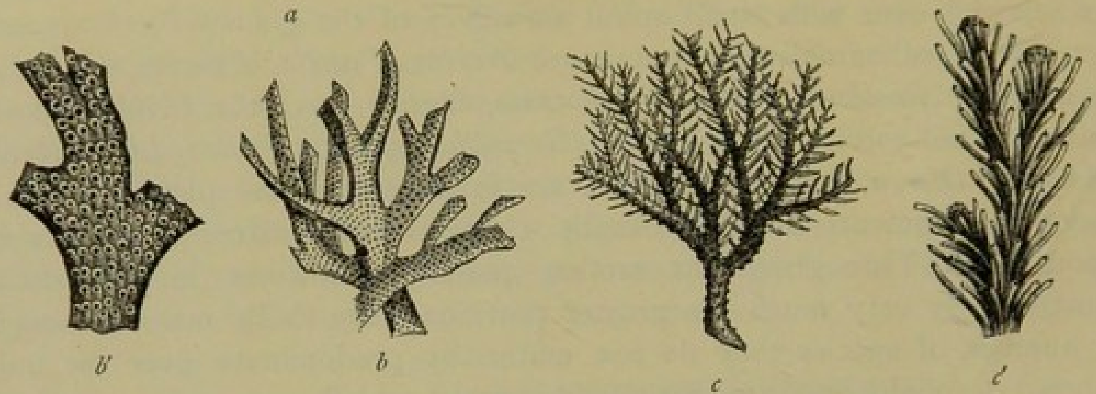


FIG. 106. Polyzoa of the Great or Bath Oolite.
a. Eschara Ranvelliana; a'. Portion enlarged. b. Mesentesipora (Bidiastopora) cervonensis; b'. Portion enlarged. c. Pustulopora (Entalophora) cellaroides; c'. Portion enlarged.

The characteristic and abundant *Brachiopoda* are *Terebratula maxillata*, *T. digona*, *Rhynchonella concinna*, and *Rh. obsoleta*.

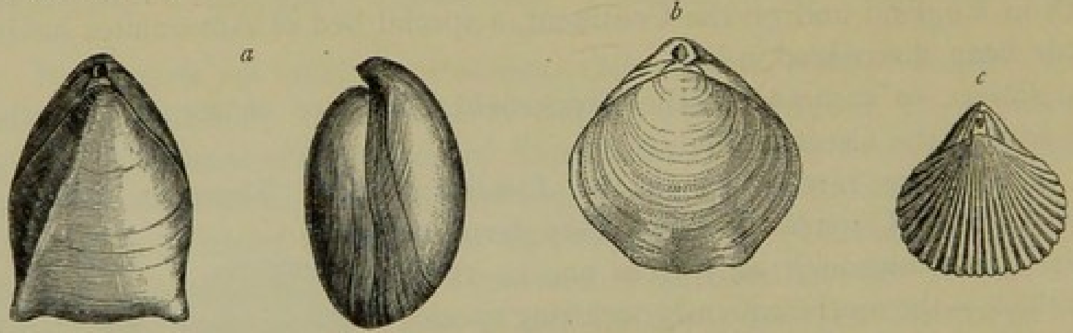


FIG. 107. Great Oolite Brachiopoda.
a. Terebratula digona, Sby. *b. T. maxillata*, Sby. *c. Rhynchonella concinna*, Sby.

The Mollusca are extremely numerous. Amongst the most characteristic are,—

Ostrea Sowerbyi, *Morr. & Lyc.*
Perna rugosa, *Goldf.*
Macrodon Hirsonensis, *D'Arch.* Pl. IX, fig. 11.
Tancredia donaciformis, *Lycett.* Pl. IX, fig. 3.
Hinnites velatus, *Goldf.* Pl. IX, fig. 6.
Pteroperna costatula, *Desl.* Pl. IX, fig. 7.
Pachyrisma grandis, *Morr. & Lyc.* Pl. IX, fig. 10.
Trigonia Moretoni, *Morr. & Lyc.*
Placunopsis Jurensis, *Ræm.*
Nerinæa Voltzii, *Desl.* Pl. IX, fig. 15.
Alaria trifida, *Phil.* Pl. IX, fig. 9.
Purpuroidea Moreausia. Pl. IX, fig. 16.
Trochotoma obtusa, *Morr. & Lyc.* Pl. IX, fig. 12.
Cylindrites bullatus, *Morr. & Lyc.* Pl. IX, fig. 14.
Pileolus plicatus, *Sby.* Pl. IX, fig. 13.
Ammonites Waterhousii, *M. & L.* Pl. VII, fig. 7.
Nautilus Baberi, *Morr. & Lyc.*
Belemnites bessinus, *D'Orb.*.

A large proportion of the fossils have been rendered imperfect by the attrition to which they have been exposed. The univalves have often lost their ornamentation, the valves of the bivalves are separate, and the echinoderms are in detached segments. There are whole beds of comminuted shells, shell-grit, and consolidated shell-sand, more or less fine—all indicating a shallow sea with drifting currents and littoral conditions.

The remains of *Fishes* are also scarce, and generally fragmentary and

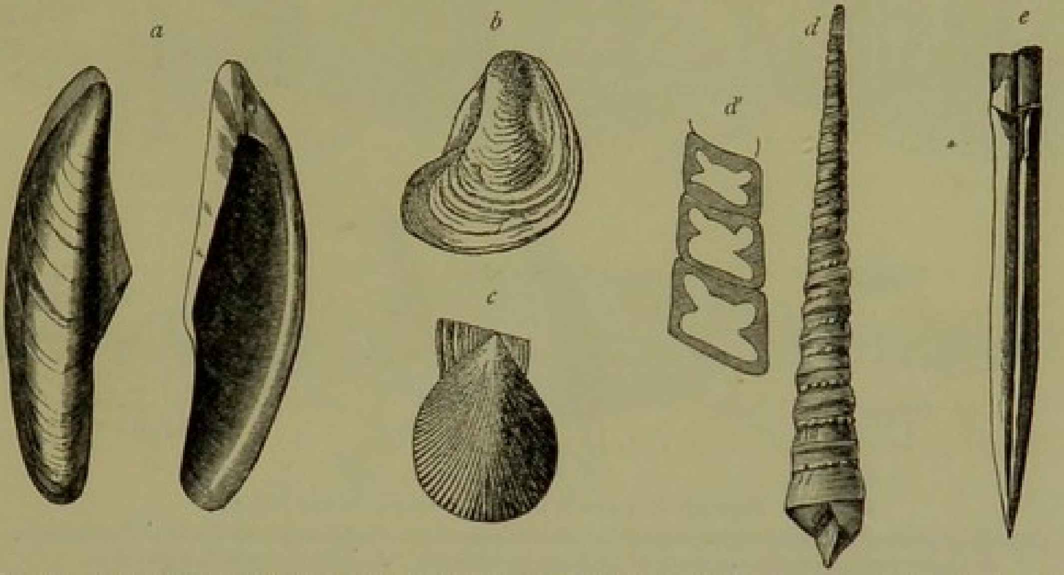


FIG. 108. *a. Gervillia monotis*, Deslong. *b. Ostrea Sowerbyi*, Mor. and Lyc. *c. Pecten divaricatus*, Phil. *d. Nerinæa funiculus*, Deslong.; *d'*. section of same. *e. Belemnites Bessinus*, D'Orb. $\frac{2}{3}$.

rolled. They are confined to a few detached teeth and vertebræ of fishes, *Pycnodus*, *Hybodus*, and *Strophodus*, with some scales of *Lepidotus*.

Although *Reptiles* are far from being so numerous as in the Lias, they are of very high interest. According to Phillips we now meet with the first of the land Chelonians (Fig. 109, *d*), together with two of the extinct terrestrial or partly terrestrial reptiles. The first in the order of discovery is the *Teleosaurus*, a genus of Mesozoic Crocodiles, first occurring in the Upper Lias of Ilminster and Whitby. It differs from crocodiles in that, whereas the vertebræ in all the recent crocodiles are *procœlian*, that is to say, convex behind and concave in front, those of these older Mesozoic Crocodiles are all '*amphicœlian*'—that is to say, concave on both sides, like those of Fishes. In the number of the vertebræ they resemble, however, the existing crocodiles; as also in the form and position of the teeth, and in having a dermal armour composed of scutes.

Owing to their predaceous habits, and the length of the jaw, these creatures were peculiarly liable to the loss of their teeth, and to provide against this great expenditure, the teeth, as they were successively pushed out or lost, were constantly replaced by others at their base. The Oolitic Teleosaurians had about 140 teeth; they are uniformly striated, the striæ being more prominent toward the point and finer toward the base.

The length of the head of Teleosaurus is from 2 to 3 feet, varying according to the species. The beak-like mouth is very narrow and prolonged, like that of the Gavial of the Ganges and the sharp-nosed Crocodile of San Domingo, to which the genus is apparently closely allied: and, as with them, the nostrils open externally near the end of the beak.

The Teleosaurus seems to have been about the same size as the

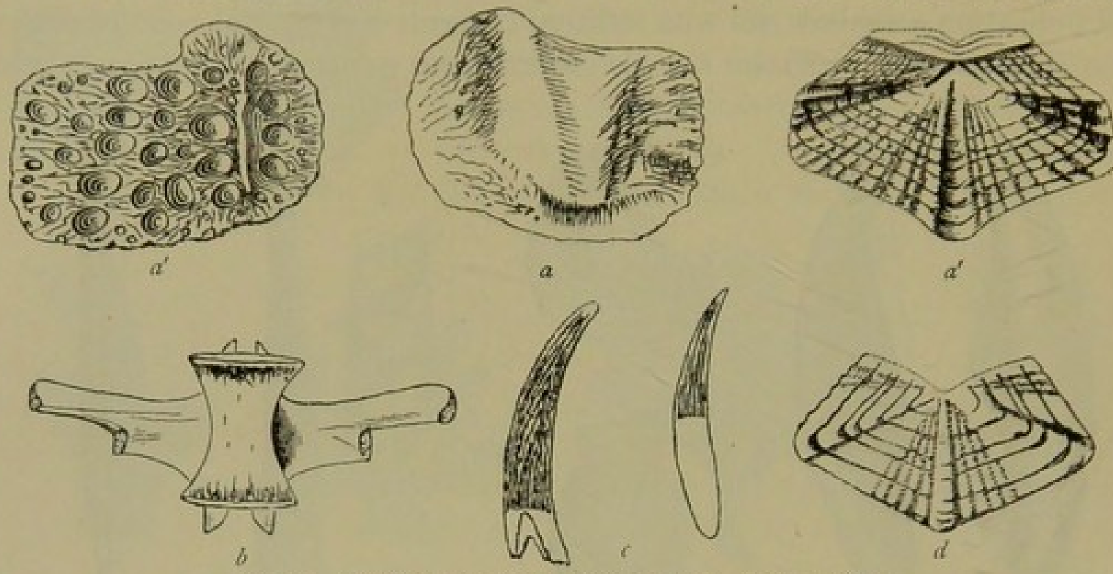


FIG. 109. Reptilian Remains of the Great Oolite. (From Phillips.)
a. Outside of scute of Teleosaurus brevidens. a'. Inside aspect. b. Vertebra, ½. c. Teeth of Teleosaurus. d. Outside of middle dorsal scute of Testudo Stricklandi. d'. Inside of another specimen.

existing Gavial, and, like it, probably lived more in the water, where it fed upon fishes, than the crocodile, which feeds upon land animals also.

In a bed of Great Oolite near Cirencester, some curious smooth oval bodies filled with spar, 1¾ inches long and 1 1/10 broad, have been found. Professor Buckman considered that they may probably be the fossil eggs of *Teleosaurus*.

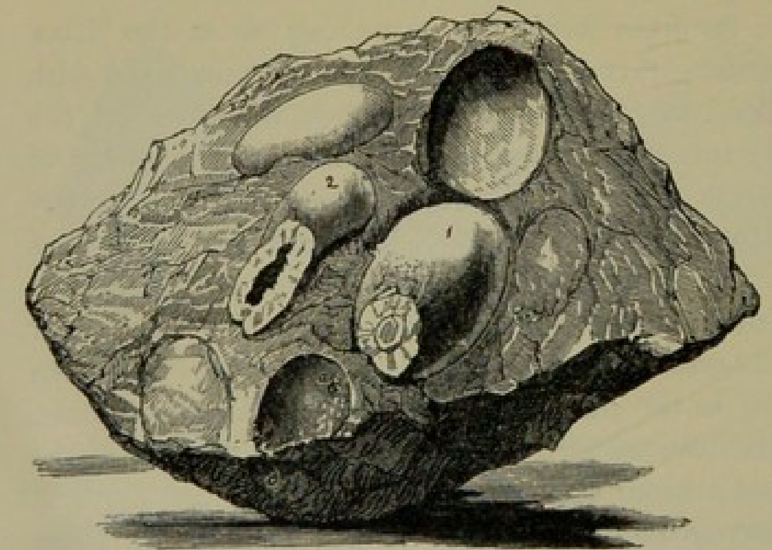


FIG. 110. Oolite with imbedded group of Reptilian eggs; Great Oolite, Cirencester. (Buckman.)
1. *Egg filled with crystals of carbonate of lime.* 2. *Egg laterally squeezed and lined with crystals of carbonate of lime.*

M. E. Deslongchamps, in an important paper[1] on the family of Teleosaurians, in which are included Steneosaurus and other allied genera (in all twenty-eight species), has given their geological range and distribution. This extends, in France, from the Inferior Oolite to the Kimmeridge Clay. Of one species, *T. Cadomensis*, characteristic of the Fuller's-Earth in Normandy, and occurring also in the Great Oolite of this

[1] 'Bull. Soc. Géol. France,' 2me sér., vol. xxvii. p. 299. See also a recent excellent paper by Mr. A. S. Woodward on Fossils and Crocodiles in 'Proc. Geol. Assoc.' vol. ix. p. 288.

country, the remains are so abundant that he was enabled to make a remarkably complete restoration. Of this a reduced figure is here given. It is one of the smaller species, not exceeding 7 to 8 feet in length. Other species attain a length of from 15 to 20 feet.

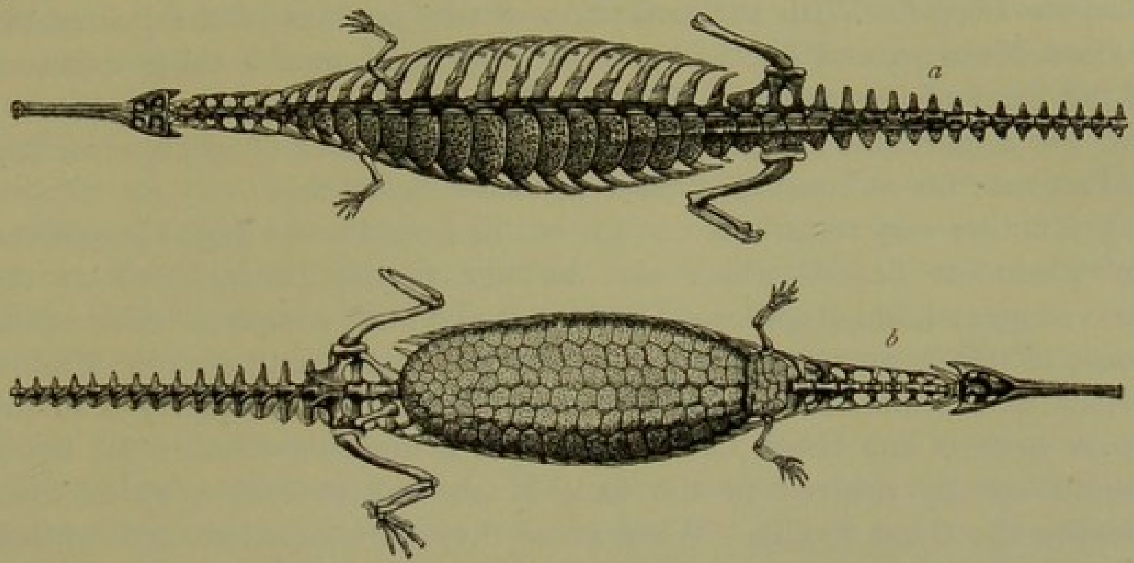


Fig. 111. Restoration of Teleosaurus Cadomensis: reduced from the figures of M. E. Deslongchamps.
a. View of back of an individual about 7½ feet long. b. Ventral surface of the same.

A characteristic Dinosaur of this period is the *Megalosaurus* (*M. Bucklandi*), or, as its name signifies, the 'great lizard.' Phillips remarks that, though not the largest of primæval reptiles, it had no rival among carnivorous land reptiles: it was 25 to 30 feet long; that its hind feet

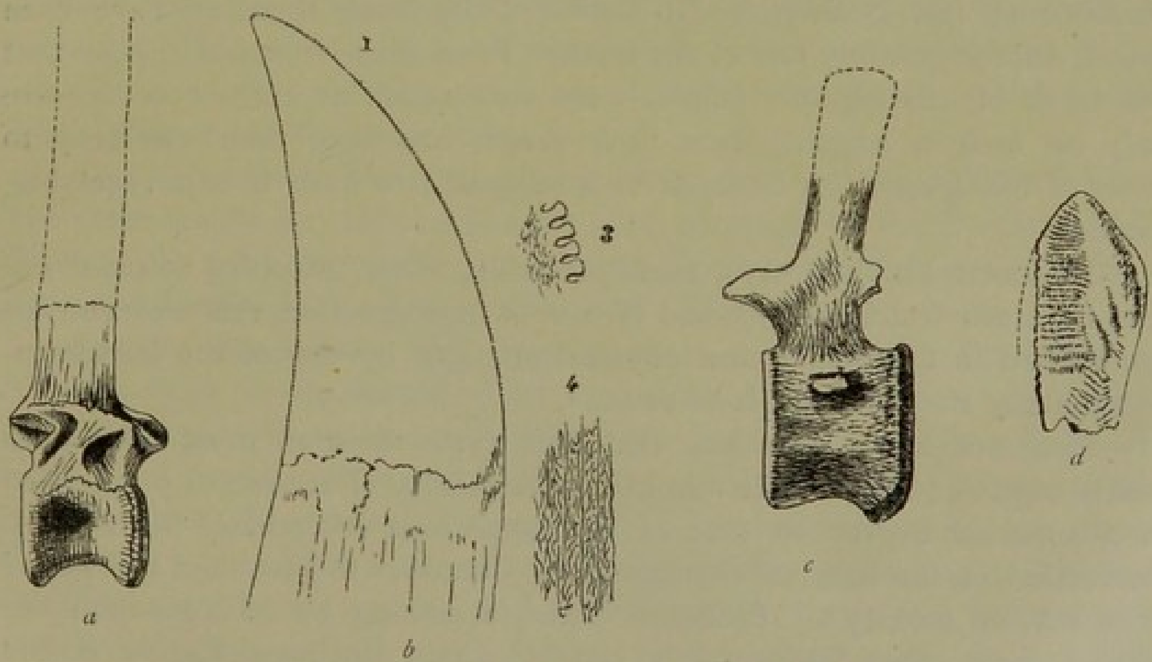


Fig. 112. Reptiles of the Great Oolite. (From Phillips.)
Megalosaurus,—*a. Dorsal vertebra*, $\frac{1}{10}$. *b. Tooth;* 1. *Outline*, nat. size. 3. *Crenulated edge*, enlarged. 4. *Striated surface.* Cetiosaurus,—*c. Caudal vertebra*, $\frac{1}{10}$. *d. Tooth*, nat. size.

were of crocodilian type, with strong compressed claw-bones; and that it had no dermal scutes.

That it was carnivorous and very destructive is shown by its powerful, pointed, and trenchant teeth, which are smooth and polished, and have finely serrated edges. On each side of the jaw there is a prominent sabre-tooth. The back teeth are much diminished in size, as in the Monitor Lizard. With the exception of two portions of the jaw in the Oxford Museum, and another portion from Sherborne, nothing is known of the head of this animal. The dorsal vertebræ are slightly bi-concave: and are remarkable for their long neural spines, some of which, according to Professor Owen, must have been 14 inches in length.

Another very remarkable reptile of this period is the huge *Cetiosaurus*, or 'whale-like lizard,' which also belongs to the *Dinosaurians* or the class of great Land Reptiles. The largest and most complete series of the bones of this huge animal that have been procured are those from Enslow Bridge quarry, about eight miles north of Oxford. This quarry is in the upper beds of the Great Oolite; but it is a question whether the bones should not be referred to the base of the Forest-marble, which there overlies the Great Oolite. When found they were detached and crushed into innumerable fragments, but have been so carefully put together that the specimens are now entire, though somewhat flattened.

Amongst the bones found at Enslow Bridge are two gigantic femurs, five feet four inches in length; the vertebræ are from eight to eleven inches in diameter; and the monstrous ribs are more than five feet in length. There are also in the Oxford Museum a pair of scapulæ, which measure 4½ feet in length. No bones of the head, however, have been found, except possibly two of the teeth. From these it would appear that the teeth of this gigantic animal were very small, as these two measure only an inch in length; from their shape, and from their similarity to those of the *Iguanodon*, *Cetiosaurus* is supposed to have been a vegetable-feeder.

Professor Phillips[1] says, that 'probably, when "standing at ease," not less than ten feet in height, and of a bulk in proportion, this creature was unmatched in magnitude and physical strength by any of the largest inhabitants of the Mesozoic land or sea[2].'

Professor Owen considers that this great Saurian must have been partly aquatic; and, 'while admitting the faculty of terrestrial progression in a superior degree to that of the amphibian crocodiles,' he believes, 'nevertheless, the habitual element of the Cetiosaur to have been the waters of a sea or estuary[3].' Professor Owen, reasoning by analogy from the size of some other Dinosaurians, concludes that the huge Enslow reptile had probably a length of 35 to 37 feet for the trunk and tail. To this

[1] 'Geology of Oxford,' p. 293.
[2] Some American Dinosaurs have, however, since been found which exceed these dimensions.
[3] Palæontographical Society's 'Monographs,' Mesozoic Reptilia for 1875, p. 41.

would have to be added the length of the head and neck, so that the entire length of the animal may have been from 40 to 45 feet.

The Great or Bath Oolite is succeeded by irregular beds of clay, fissile oolites, argillaceous limestones, and calcareous sandstones with oblique lamination, forming a series known as the Bradford Clay and Forest-marble.

Bradford Clay. Although the Bradford Clay forms in Somerset and in the neighbourhood of Bath and Bradford a deposit 60 to 100 feet thick, it is of very local occurrence, and is elsewhere subordinate to the Forest-marble, the clay beds gradually thinning out to the northward, before reaching the Cotteswolds. It derives its name from the town of Bradford in Wiltshire, where it is best exhibited. It there consists of a pale blue clay immediately overlying the compact white upper limestone of the Great Oolite. The surface of that limestone evidently for a time formed a bare rocky sea-bed, on which flourished a complete colony of the Pear-Encrinite (*Apiocrinus Parkinsoni*). Stems and roots of these crinoids, in the position in which they grew, are attached in vast numbers to the surface of the limestone; but, though the stumps remain, the stems, bodies, and arms have been so broken and scattered in and under the superincumbent argillaceous beds, that a nearly perfect specimen is excessively rare.

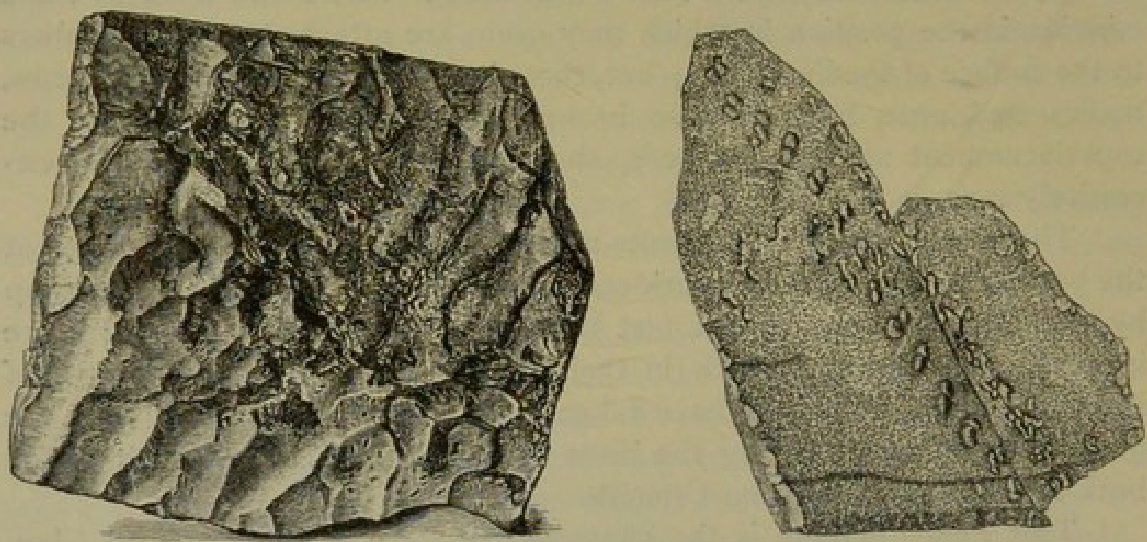
That these detached fragments must themselves have been exposed at the bottom of the sea for a considerable time before they were covered up by the clay is shown by the fact that many of the detached plates are invested with Serpulæ, which in their turn are covered by a growth of Polyzoa. This could only have taken place before the deposition of the great body of mud forming the mass of the Bradford clay, which buried both the dead and the living Crinoids.

This Pear-Encrinite is the characteristic fossil of the Bradford Clay. The other fossils are, for the greater part, common to the Forest-marble. Those which most frequently occur are the *Terebratula digona*, *T. coarctata*, *Avicula echinata*, *Pecten hemicostatus*, and *Cidaris Bradfordensis*.

Forest-Marble. This Formation is most largely developed at Abbotsbury in South Dorset, where it consists of thin seams of argillaceous and rubbly grey limestone, alternating with beds of clay, with a thickness of 450 feet; while the Great Oolite is wanting. As the Forest-marble ranges north, it gradually diminishes in importance,—and the Great Oolite sets in,—until in Somerset the Forest-marble is reduced to 150 feet, in Gloucestershire to 40 feet, and in Oxfordshire to 25 feet in thickness, and it does not extend much farther to the North-east. It has been suggested that the lower part of the Forest-marble in Dorset may be the equivalent of and synchronous with the Great Oolite of the Bath district.

Amongst the places where this formation is well exhibited are Paulton, between Fairford and Cirencester, and Enslow Bridge, Witney, and Islip, near Oxford. Its name was given by William Smith, in consequence of the extent of this formation in the Forest of Wychwood, between Witney and Charlbury, where some of the shelly beds are compact enough to be used as a rude marble, but it is not now worked for this purpose.

Some of the fissile limestones in these districts form large thin slabs, sometimes not more than half-an-inch thick, much used for roofing, fencing, and paving. These slabs are frequently one mass of fossils, and on their surfaces are seen numerous single valves of *Pecten*, *Rhynchonella*, and a small *Ostrea*, etc., all much compressed and broken. There occur also fragments of the spines and plates of Echinoderms; and with these are numerous tracks of Annelids, Molluscs, and small Crustaceans. It is very striking to see, in some of the quarries, the extent to which the slabs are ripple- and track-marked, not only on one level, but on a succesion of levels, showing that the successive layers were deposited in a shallow



a *b*

FIG. 113. Slab of Forest Marble, showing tracks and ripple-marks. Enslow Bridge.
a. Ripple and Reptile (Rhynchosaurus) marks on a slab of Forest-Marble (4 feet by 3½). *b. Track of a Crustacean* (? *on a slab of Forest-Marble from Enslow Bridge* (1 by ½ foot). Photographed from specimens in the Oxford Museum.

sea-bed undergoing slow and gradual depression. Now, these old surfaces are again brought to light after long geological ages, just as they were left by the last ripple of the water, ridged in parallel lines and covered, as in the case of existing strands or shallow banks, with the innumerable small *débris* and tracks of the marine organisms of the period.

Few of the Forest-marble fossils are peculiar to it. Fragments and logs of drifted wood (Coniferous) are common, but there are no other recognisable plant remains. The ordinary fossils are,—

Terebellaria ramosissima, *Lamx.*
Acrosalenia pustulata, *Forb.*
Rhynchonella concinna, *Sby.*
Terebratula digona, *Sby.*
Ostrea rugosa, *Goldf.*
Lima cardiiformis, *Mor. and Lyc.*
Pecten annulatus, *Sby.*
Modiola imbricata, *Sby.*
Astarte minima, *Phil.*
Trigonia costata, *Park.*

Reptiles. Few reptilian remains are found in the Forest-marble. I have described the Cetiosaurus under the head of the Great Oolite, as it is said to occur not only at Enslow Bridge, but also in the Great Oolite of Chipping Norton, Buckingham, and other places. But with regard to the huge specimen from Enslow Bridge, I believe it should be assigned to the Forest-marble. Phillips's description of the section ('Geology of Oxford,' p. 251), which is quite right, scarcely tallies with his localisation. The surface

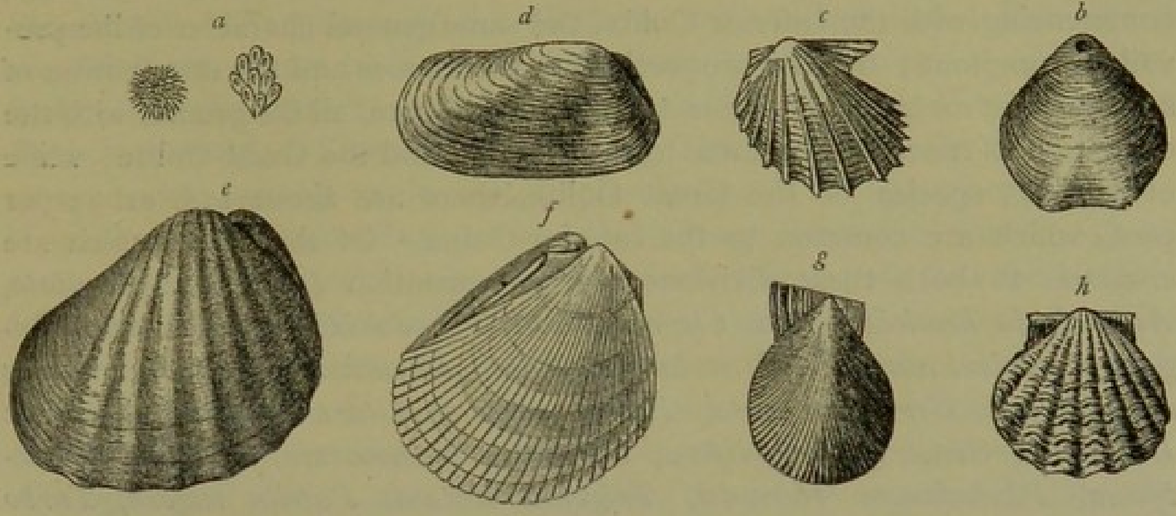


FIG. 114. Fossils of the Forest-Marble and Cornbrash.
a. Diastopora diluviana, M. Edw. *b. Terebratula obovata.* *c. Avicula echinata.* *d. Myacites Beanii.* *e. Pholadomya deltoidea.* *f. Lima cardiiformis*, F. *g. Pecten divaricatus.* *h. P. vagans.*

of the Great Oolite in the Cetiosaurus quarry forms a well-marked line of slight erosion, which is strewed at places with pebbles of consolidated marl and pierced by Annelid-like borings. It was one to two feet above this that the bulk of the great bones were found, and lately a vertebra of Cetiosaurus has been found near the top of the series within two feet of the Cornbrash. Of the other localities I cannot speak from personal knowledge.

The Cornbrash, which forms the upper division of the Lower Oolites, consists of rubbly, thin-bedded, or hard nodular oolite, with intercalated yellow marl or clay. It forms good corn-growing soil, which, owing to its broken and rubbly (brashy) character, acquired the local name of 'Cornbrash.'

Although generally not more than from 10 to 15 feet in thickness, it is nevertheless continuous across England, from the coast of Dorset to that of Yorkshire. It is much used for rough walls, road-mending, and lime-burning. The fossils are usually badly preserved. Small broken fragments are, however, plentiful. The *Homomya* and *Pholadomya* (generally only in casts) are very large size. The latter not unfrequently occurs in the Cornbrash, in the same natural position in the rock which it had when living in the sea-bed.

The characteristic fossils of the Cornbrash are,—

Echinobrissus clunicularis, *Llhwyd.*, Pl. VIII, fig. 2.
Terebratula perovalis, *Sby.*
T. obovata, *Sby.*
Avicula echinata, *Sby.*
Pholadomya deltoidea, *Sby.*
Lima duplicata, *Sby.*
Homomya gibbosa, *Sby.*
Myacites Beanii, *Lyc.*
Gresslya peregrina, *Phil.*
Trigonia Moretoni, *Mor. and Lyc.*
Ammonites Herveyi, *Sby.*, Pl. VII, Fig. 6.
A. discus, *Sby.*

With the Cornbrash ends the division of the Lower Oolites. In them, commencing with the Inferior Oolite, the same general character of life prevails throughout; but the proportions of the classes and the distribution of species differ materially. Thus, taking the Mollusca, all the genera, with the exception of nine, are common to the Inferior and the Great Oolite; while of the 525 species of the Great Oolite, there are about 175, or 33 per cent., which are common to the Inferior Oolite. Of the fossils which are common to both these divisions, we may mention *Isastræa explanulata, Acrosalenia hemicidaroides, Clypeus Plotti, Pseudodiadema depressum, Pygaster semisulcatus, Terebratula maxillata, Rhynchonella obsoleta, Lima cardiiformis, Gervillia acuta, Perna rugosa, Astarte elegans, Cardium Buckmani, Goniomya angulifera, Homomya crassiuscula, Modiola Sowerbyana, Pholadomya Heraulti, Trigonia costata, Patella rugosa, Turbo capitanus, Belemnites Blainvillei, Strophodus magnus.*

The Lower Oolites of the Midland Counties. In the neighbourhood of Bath this division of the Oolitic series has a total thickness of nearly 600 feet; but as it ranges north-eastward, it becomes so reduced that between Banbury and Towcester it is little more than 100 feet thick: all the lower stages have thinned out, and the Cornbrash and the Great Oolite alone represent the Lower Oolites. Beyond this, we enter a new area in which different conditions prevailed—those conditions being on the whole more estuarine and fluviatile. It is to the researches of Professor Morris [1], Mr. S. Sharp [2], and Professor Judd [3] that geologists are mainly indebted for the details of this district and for the correlation of the beds with those of the same age to the southward.

In the Northampton and Stamford district, the beds which correspond to the Inferior Oolite of Gloucestershire, and which, commencing near Towcester, gradually expand northward, are:—

1. **The Lincolnshire Limestone.** This consists of a light-coloured marly and oolitic limestone, which attains further north a maximum thickness of about 200 feet, and contains a group of fossils which, although in a number of cases specifically distinct from those of the Inferior Oolite

[1] 'On some Sections in the Oolite districts of Lincolnshire;' Q. J. Geol. Soc. vol. ix. p. 317.
[2] 'On the Oolites of Northamptonshire;' *Ibid.* vol. xxvi. p. 354, and vol. xxix. p. 225.
[3] 'Geology of Rutland;' Mem. Geol. Survey.

of Cheltenham, have certain species in common with it, including such characteristic forms as *Ammonites Murchisonæ*, *Rhynchonella spinosa*, *Terebratula fimbria*, etc.

2. **The Northampton Sands,** which underlie the limestone, consist of a series of sandy and ferruginous beds with some calcareous bands, rarely more than 100 feet thick. They are in great part unfossiliferous, with the exception of the upper part, which constitutes locally an estuarine deposit, very like in aspect to that which underlies the Great Oolite at Stonesfield. The genera of the Mollusca are analogous, but the species are different. These beds are best developed at Collyweston, near Stamford, where they are characterised by *Pholadomya fidicula*, *Gervillia acuta*, *Pteroceras Bentleyi*, *Trigonia compta*, etc. The surface of the stone is also covered with Annelid tracks and ripple-marks. This upper portion of the Northampton sands has been termed the 'Lower Estuarine' series. These sands hold the same relation to the Lincolnshire limestone that the Midford Sands hold to the Inferior Oolite, but they are on a higher horizon, namely that of the Ammonites Murchisonæ zone of the Inferior Oolite. It is in the lower part of these sands that the Northamptonshire iron-ore occurs. This ore consists of a hard, dark, greenish-grey carbonate of iron, with grains of quartz and oolitic grains, the whole weathering into the brown hydrated peroxide of iron. These beds, though generally destitute of fossils, are fossiliferous in places, the species being those of the Inferior Oolite.

It would seem that during the early Oolitic period, the Gloucestershire and Midland areas were separated by a barrier, which later on was submerged so as to allow of the extension continuously northward of the overlying Great Oolite and Cornbrash, which consequently retain more unbroken their petrological and palæontological sequence. At the same time, a Second Estuarine series with Unio, Cyrena, and land plants, marks the insetting of the Great Oolite in the Midland area.

The Lower Oolites of Yorkshire. The land and estuarine conditions become more predominant as the strata range further north; and in Yorkshire they constitute a series of estuarine shales and sandstones, with plant-remains and poor coal-beds, alternating with oolitic marine beds; the whole presenting so widely different an aspect to the strata of the south that the exact correlation of the strata long remained doubtful, and is now only established broadly and not for the several minor divisions. The well-known work of Professor Phillips[1] and the more recent researches of Mr. Leckenby[2], Mr. W. H. Hudleston[3], and others, have established the

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[1] 'Geology of Yorkshire,' vol. i., 3rd edit.

[2] 'Quart. Journ. Geol. Soc.' vol. xix. p. 519; vol. xx. p. 74.

[3] 'On the Palæontology of the Yorkshire Oolites,' Geol. Mag. 1880–85.

following order of succession in the Lower-Oolite series of Yorkshire in descending order:—

Cornbrash, with *Avicula echinata, Terebratula obovata*, etc.	12 feet.
Upper Estuarine Shales and Sandstones	120 „
Scarborough Limestone, and Stonecliff-Wood Series	60 „
Middle Estuarine Shales and Sandstones, with the Gristhorpe plant-bed ...	80 „
Millepore-oolite, with *Cricopora straminea, Gervillia Hartmanni*, etc. ...	20 „
Lower Estuarine Shales and Sandstones, with numerous plant remains ...	250 „
Dogger Sandstones and Ironstone	50 „
Lower Sands and Sandstones	25 „

Of these only the upper estuarine beds are now considered to represent the Great Oolite of the south. The Millepore-oolite and the Dogger series belong certainly to the Inferior Oolite; and the Scarborough limestone and Middle Estuarine strata are now also generally referred to the same series. The first contain but few fossils. Conspicuous amongst the fossils of the Scarborough beds are *Belemnites giganteus, B. elongatus, Ammonites Blagdeni*, and *Alaria hamulus*; species of *Gervillia, Myacites* (*M. Beanii*), *Cucullæa* (*C. cancellata*), etc. abound.

The Middle and Lower Estuarine series are remarkable for their abundant plant-remains. These consist chiefly of Ferns, belonging to the genera *Ctenis* (*C. falcata*), *Phlebopteris* (*Ph. Phillipsii*), *Sphenopteris* (*S. Williamsonis*), etc.; Cycads of the genera *Otopteris* (*O. Beanii*), *Pterophyllum* (*Pt. pectinoideum*), etc., are also common: of Conifers there are several species of *Walchia, Pachyphyllum*, etc.; while the lower series has some great Equisetaceæ and Cycads peculiar to it. Scales of Araucarian seeds are found in the shales. Another coniferous plant of these beds is the *Brachyphyllum mammillare*. A common species of Equisetaceæ is the *Equisetum columnare*.

According to Professor Phillips the flora of these beds consists of—

Equisetaceæ	2 species.
Lycopodiaceæ	1 „
Ferns, including some Tree-ferns	49 „
Cycads	22 „
Conifers	10 „

There are also a few Algæ. Ferns and Cycads form the predominant vegetation.

It is to the growth of these plants, or chiefly so, *in situ*, that the three coal-seams of this series seem to be due. Only one seam has been worked. It varies in thickness from 1 to 1½ feet.

The Millepore-limestone is characterised by its Polyzoa (*Cricopora*), Echinodermata, and Mollusca; and the Dogger series by numerous shells replaced by spathic iron, including *Cypricardia cordiformis, Modiola furcata, Cucullæa reticulata, Trigonia striata*, etc. The lower beds contain also the characteristic Inferior-Oolite Brachiopods, *Terebratula fimbria* and *Rhynchonella spinosa*, and the *Ammonites Humphriesianus*. The whole series attains a thickness of from 500 to 600 feet.

It would appear, then, that in the South of England there was, at the early Oolite period, an open sea of moderate depth, in which from time to time banks of coral flourished, and at other times, more littoral conditions prevailed; and that into this sea one river at least flowed in the Stonesfield district. Further north, however, and beyond the Buckinghamshire barrier, many rivers apparently debouched into the Oolitic sea, and by these the sand, silt, and plant *débris* of the great Yorkshire estuary were brought down. There was evidently a large continental land in close proximity to this area. This land has been placed by some to the west of the Oolitic district, that is, in the Cumberland and Welsh area. These may then have formed islands, but I think it more probable that the continental Palæozoic land lay to the eastward. This land, now covered by Mesozoic and Tertiary strata, then extended to the distant Scandinavian mountains, and formed an area which, with certain changes of level, was persistently maintained throughout all the earlier Mesozoic times, and was only finally in greater part submerged during the Cretaceous and Tertiary periods.

CHAPTER XIV.

THE JURASSIC SERIES (*continued*): THE MIDDLE OOLITES.

THEIR DIVISIONS AND RANGE. THE KELLOWAYS ROCK. ORGANIC REMAINS. THE OXFORD CLAY. STRUCTURE. MINERAL PRODUCTS. THICKNESS. ORGANIC REMAINS. THE CORALLINE OOLITE. ITS DISTRICT AND STATIGRAPHICAL DIVISIONS. TYPE SECTIONS OF DORSETSHIRE, OXFORDSHIRE, CAMBRIDGESHIRE, AND YORKSHIRE. PALÆONTOLOGICAL RELATIONS. CORAL BANKS. CHARACTERISTIC FOSSILS. SUBSIDING AREA.

THE Middle Oolites, which succeed conformably to the Cornbrash, and which, like the Lower Oolites and Lias, range from the coast at Weymouth across England to the coast of Yorkshire, south of Scarborough, consist, in descending order, of—

3. Coralline Oolite, or the Corallian group.
2. Oxford Clay, or the Oxfordian group.
1. Kelloways Rock, or the Callovian group.

FIG. 115. Diagram-Section of the Middle Oolites. (Phillips.)
f. Inferior Oolite. h. Great Oolite. j. Cornbrash. k. Oxford Clay and Kelloways Rock. l. Calcareous Grit. m. Coral Rag (Coralline Oolite). n. Kimmeridge Clay.

The Kelloways Rock in the south of England is so subordinate to the Oxford Clay, that it is rather an appendage to the more important overlying beds of clay. At Kelloway's Bridge, near Chippenham, from which place the rock takes its name, it is a grey sandy fossiliferous limestone, only eight to ten feet thick, but with several characteristic fossils. In Yorkshire it forms a calcareous sandstone, 80 feet thick, with palæontological characters much more distinctive, so that there, as on the continent, it constitutes a well-recognised division, with a peculiar fauna of 168 species, of which fifty-six are, according to Mr. Etheridge, common to the Cornbrash, and sixty to the Oxford Clay. There are no fewer than forty-one Ammonites.

The following are some of the characteristic fossils of the Kelloways Rock:—

Ammonites Calloviensis, *Sby.*
„ athletus, *Phil.*
„ Gowerianus, *Sby.*
Belemnites Owenii, *Pratt.*
Ancyloceras Calloviense, *Mor.*
Gryphæa bilobata, *Sby.*
Lima notata.
Lucina lirata, *Phil.*
Avicula ovalis, *Phil.*
Alaria bispinosa, *Phil.*

Mr. Hudleston remarks on the sudden appearance and abundance of Ammonites in the Kelloways Rock of Yorkshire, while only one species is there found in the underlying Cornbrash, as a striking palæontological feature.

Organic Remains. No Plant remains, no Corals, no Polyzoa, and no Protozoa have been noticed; only three Echinodermata, and very few Annelids and Crustacea.

There are ten species of Brachiopods, which show relations on the one hand to those of the Cornbrash, and on the other to those of the Oxford Clay and Coralline Oolite.

The Lamellibranchs and Gasteropods likewise show a considerable proportion common to the underlying and the overlying strata; but there are, at the same time, a certain number peculiar to the Kelloways Rock, especially in Yorkshire, such as *Corbis lævis*, *Cucullæa æmula*, *Modiola Morrisii*, *Alaria arsinoe*, *Chemnitzia lineata*, and *Patella graphica*; while no less than seventeen species of Ammonites are restricted to this zone. The *Nautilus hexagonus* ranges from the Cornbrash to the Coralline Oolite.

On the Continent the Kelloways Rock forms a division of almost equal importance with the Oxford Clay.

The Oxford Clay.

This Formation, overlying the Kelloways Rock, consists of a great mass of dark-bluish tenacious clays, generally calcareous, with here and there a layer of grey argillaceous limestone, and occasional seams of septaria. The petrological characters are very uniform throughout its range in England. Iron-pyrites occasionally occurs in small nodules, or segregated in and around the fossils. There are also in places, as in so many other clays, crystals of selenite (see Vol. I. p. 116). As it serves for good brick-earth, pits are numerous, and the fossils easily obtained.

Some portions of the Oxford Clay are so bituminous that near Weymouth it was worked for a time for its mineral oil; it has also been used for making gas. It is probable that this bituminous matter has been derived from the decomposition of animal substances.

In the neighbourhood of Weymouth the Oxford Clay is estimated to be about 500 feet thick, which becomes reduced to 300 feet in Wiltshire and Oxfordshire.

In the Eastern Counties it attains a greater thickness, and underlies much of the marsh- and fen-lands of Huntingdon and Lincolnshire. In Yorkshire it appears on the coast of Gristhorpe and Clayton Bays, with a thickness of about 140 feet, forming a range of cliffs capped by a bold cornice of Lower Calcareous grit.

The lower beds of the Oxford Clay are often very destitute of fossils; but in the middle and upper beds fossils are abundant and well preserved.

Plants. Very few plant-remains, properly so called, have been found in the Oxford Clay, but fragments of drifted wood, worn and covered by Serpulæ, showing that they were floated about in the old Oxfordian sea, are not uncommon. All we know of this wood is that it is coniferous.

Protozoa. Foraminifera are sometimes common; the *Cristellaria crepidula* often abundant.

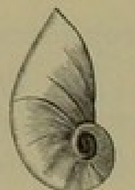

Fig. 115*. *Cristellaria crepidula* (Fichter and Moll.) × 25.

Corals, as might be supposed from the nature of the deposit, are rare, or altogether absent, with the exception of the small cosmopolitan *Anabacia orbulites*.

One **Annelid**, the *Serpula vertebralis*, is common, attached to dead shells and drifted wood.

Echinodermata are only a little less scarce than corals.

The rarity of **Polyzoa** and **Brachiopoda**, which contrasts so strongly with the abundance of **Cephalopoda**, is a fact to be noticed. With respect to Ammonites, the group of the *Ornati*, of which a typical species is the *Ammonites Duncani*, particularly characterises the Oxford Clay. Other characteristic species are *Am. Bakeriæ*, *Am. Jason* (Pl. VII, fig. 8), *Am. Comptoni*, *Am. Lamberti*, *Am. oculatus*.

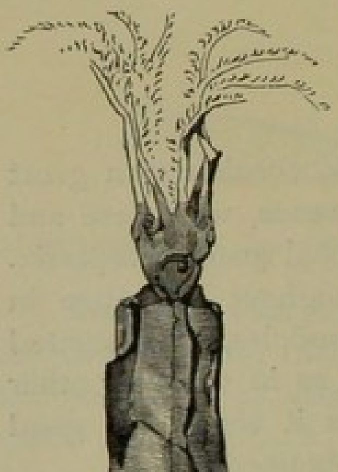

Fig. 116. *Belemnoteuthis antiquus*. From a specimen in the British Museum, ½.

In the railway-cutting at Christian-Malford, near Chippenham, Ammonites were found in a remarkable state of preservation. Not only were their shells preserved, but a large number of the *Ammonites Jason* were quite entire, though much compressed, and had the fragile beak-like projections at the aperture of the shell preserved. It is rare generally to find more than the guard or rostrum of Belemnites; but there the phragmacone, and even considerable portions of the conotheca, with the nacreous shelly covering of *Belemnites* and its allied genus *Acanthoteuthis* (*Belemnoteuthis*), together with the enclosed ink-bag, and in some cases the horny hooks of the tentacles, are likewise preserved, showing that the animals were imbedded, if not alive, immediately after death, before any parts of the soft body had become detached and separated.

According to Professor Phillips, the Belemnites, which characterise the Oxford Clay, belong to the groups *Hastati*, *Caniculati*, *Tornatiles*, and *Excentrici*; the common species being *B. Owenii*, *B. hastatus*, and *B. sulcatus*.

The number of the ordinary **Mollusca** is restricted, and many of the genera are represented by single species; but the individuals of some species, such as the *Gryphæa dilatata*, occur in extraordinary abundance.

The following are some of the more characteristic species:—

Gryphæa dilatata, *Sby.*	Trigonia clavellata, *Park.*
Avicula inæquivalvis, *Sby.*	Alaria bispinosa, *Phil.*
Modiola bipartita, *Sby.*	Pleurotomaria Münsteri, *Roem.*
Pecten fibrosus, *Sby.*	Cerithium Damonis, *Lyc.*

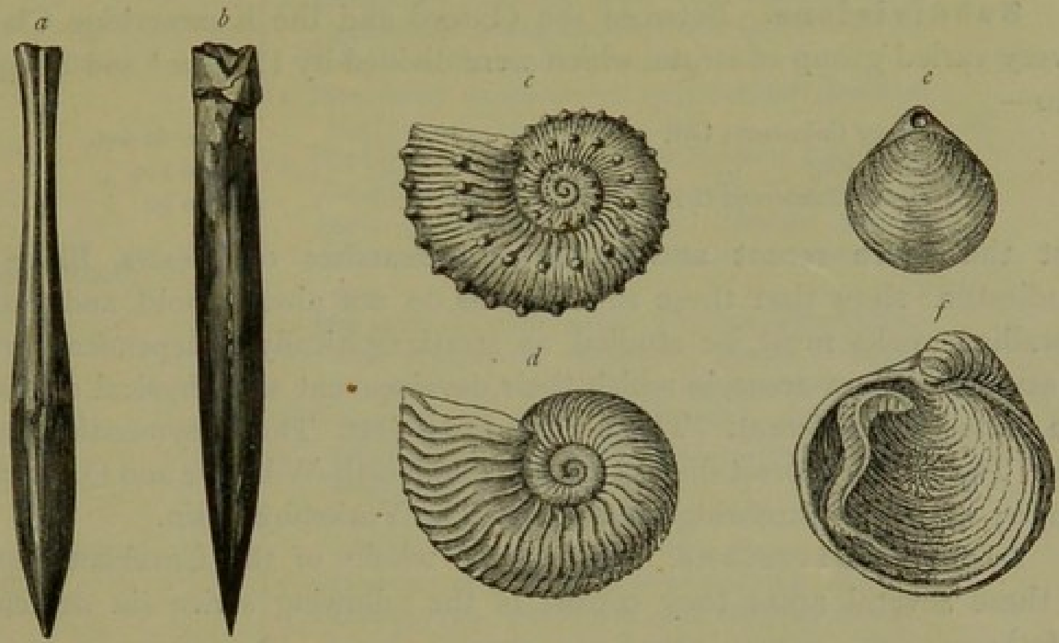

FIG. 117. Fossils of the Oxford Clay.
a. Belemnites hastatus, Blainv. *b. Belemnites Oweni*, Blainv. *c. Ammonites Duncani*, Sby. *d. Ammonites Lamberti*, Sby. *e. Terebratula impressa*, Von Buch, $\frac{2}{3}$. *f. Gryphæa dilatata*, Sby., *with attached Serpula tricarinata*, Sby.

The **Crustacea** are limited chiefly to the generally fragmentary remains of *Glyphea leptomana* and *G. Stricklandi*.

Fishes are also very few in number, and it is rare to find well preserved specimens: though in places the teeth of *Lepidotus macrorhynchus*, *Hybodus grossiconus*, and *Ischyodus Egertoni*, are far from rare.

Of **Reptiles**, Professor Phillips enumerates thirteen species, belonging to eight genera; there are two species of *Ichthyosaurus*, both different from those of the Lias, and both rare. Of the *Plesiosaurus*, there are four species peculiar to this formation, and the remains of which are sufficiently common. Some of the paddles of this creature were of great size, as much as $2\frac{1}{2}$ to 3 feet in length. One species, the *Plesiosaurus eurymerus* from Bedford, is remarkable not only for the length but also for the narrowness of its paddles.

Remains of two species of *Pliosaurus* are reported from the Oxford Clay. Another remarkable Saurian of the Oxford Clay is the *Strepto-spondylus Cuvieri*, apparently agreeing with that celebrated Honfleur Saurian in its vertebral system. As teeth of *Megalosaurus* were, however, found in association with these remains, Professor Phillips regarded it as possibly a *Megalosaurus*, 'smaller and, in some respects, different from *M. Bucklandi*,' and having, like it, ornithic proportions and analogies.

The Coralline Oolite.

(Corallian rocks of Blake and Hudleston.)

Subdivisions. Between the Oxford and the Kimmeridge Clays is a very varied group of strata, which were divided by Phillips [1] and Sedgwick into—

Upper Calcareous Grit	5 to 60 feet.
Coral Rag	10 to 120 ,,
Lower Calcareous Grit	20 to 80 ,,

But the more recent and elaborate researches of Messrs. Blake and Hudleston [2] show that these subdivisions do not always hold, and that the Corallian rocks must be studied as stratigraphically independent groups in several distinct areas, in which their development and physical conditions are materially different. These areas are:—1st. The Weymouth district; 2nd. The North-Dorset district; 3rd. The North-Wiltshire and Oxfordshire range; 4th. The Cambridge reef; 5th. The Yorkshire basin.

District Divisions. Taking the whole of the Corallian deposits in these several areas, they consist of the following series (in descending order):—

6. The Supra-Coralline beds of Weymouth and Yorkshire.
5. The Coral Rag of the Midland Counties.
4. The Coralline Oolite of Yorkshire and Weymouth.
3. The Middle-Calcareous Grit of Yorkshire.
2. The Lower Limestone, or Hambleton Oolites.
1. The Lower-Calcareous Grit.

The several deposits are generally in broad masses thinning out lenticularly, but with diameters of very unequal lengths. Nevertheless, the authors consider that, as a whole, the series can in most of the districts be divided into—

(1) An upper group, usually a reddish Calcareous Grit with variable clays, including certain oolitic iron-ores,—the Upper Calcareous Grit of Dorset and Yorkshire.

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[1] 'The Geology of Yorkshire,' vol. i., 3rd edit.

[2] 'Quart. Journ. Geol. Soc.' vol. xxxiii. p. 260, 1877. This series offers a good illustration of the variable conditions under which the Oolitic strata generally were formed.

(2) A middle group, comprising the *Florigemma* Rag, and the various limestones which represent or underlie it,—the Coral Rag or characteristic zone of Corals of Wiltshire and Oxfordshire.

(3) A lower group, consisting of yellow grits and clays in the south; in the Midland Counties chiefly of rather loose sands; and by a great thickness of solid stone in Yorkshire. This includes the *Lower Calcareous Grit*.

Local Sratigraphy. The variations in structure will be best shown by the following description of the sections at extreme and central positions. Nos. 1 and 3 are compiled from Messrs. Blake and Hudleston's paper.

1. *Dorsetshire*. Vertical rendering of the coast-section from near the Isle of Portland to Osmington[1]:—

Upper Group	1. Ferruginous clays and grits. The Sandsfoot grits with *Pecten Midas*, *Goniomya v-scripta*, *Ammonites decipiens*, *Ostrea deltoidea*, etc.	45 feet.
	2. Blue, marly, unfossiliferous clay, with two bands of hard rock. The Sandsfoot clay	40 ,,
Middle Group	3. Hard gritty limestone, with shell-beds on top; Main limestone or Trigonia-series, with *Trigonia clavellata*, *Gervillia aviculoides*, *Myacites jurassi*, *Thamnastræa arachnoides*, *Thecosmilia annularis*, etc.	30 ,,
	4. Blue marls and white oolite. The Osmington Oolites, with *Phasianella Buvignieri*, *Natica corallina*, *Lima subantiquata*, *Echinobrissus scutatus*, etc. ...	34 ,,
Lower Group	5. Calcareous grits, sands, and doggers[2]. The Bencliff Calcareous grits, with few fossils, *Gervillia aviculoides*, *Trigonia corallina*, etc.	21 ,,
	6. Clays with hard bands. The Nothe clays and grits, with *Nautilus hexagonus*, *Pecten fibrosus*, etc. ...	40 ,,
	7. Calcareous grits, with fucoidal markings and calcareous sands. Nothe grits, with *Gryphæa dilatata*, *Ostrea gregaria*, *Ammonites cordatus*, *Perna quadrata*, *Trigonia perlata*, etc.	30 ,,
		230 feet.

At Abbotsbury there is a remarkable local deposit, of considerable thickness, of a hydrated oxide of iron, with *Rhynchonella corallina*, *R. inconstans*, *Waldheimia lampas*, *Ammonites decipiens*, *Gryphæa virgula*, etc. There are also badly preserved species of *Pteroceras*, a genus rare in England but very abundant on the Continent, together with *Brachiopods*, which latter do not otherwise occur in the Corallian strata of this district. The authors consider that these beds occupy a horizon between the Sandsfoot Sands and the Kimmeridge Clay, and are possibly passage-beds.

Oxfordshire. Around Oxford, the upper group is wanting, and, at the foot of Shotover Hill, the Kimmeridge Clay rests directly and sharply on a

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[1] See also Damon's 'Geology of Weymouth and the Island of Portland.'

[2] A local term applied to certain large nodular concretions.

denuded surface of a compact shelly oolite of the middle division. The general section in this district is as under:—

Middle Division	1. Light-coloured shelly oolitic strata, with only few entire shells and some branching Corals, passing down into No. 2	16 to 20 feet.
	2. Rubbly limestone, with clay partings; massive and branching Corals abundant—*Isastræa explanata*, *Thecosmilia annularis*, *Lithodomus inclusus*, etc., some Molluscs (Ostrea, Pecten, etc.) and spines of Cidaris. *This bed represents an old Coral-bank* ...	12 feet.
	3. Calcareous sands, with *Ostrea gregaria* and a bed of hard greyish limestone, containing numerous *Lima læviuscula*, *L. rigida*, *Pecten lens*, *P. vimineus*, *Astarte ovata*, *Gervillia aviculoides*, *Natica arguta*, *Chemnitzia Heddingtonensis*, *Phasianella striata*, spines of *Cidaris florigemma*, *Belemnites abbreviatus*, etc.	7 "
Lower Division	4. Small pebbly bed, with *Ammonites cordatus*, *A. excavatus*, etc.	1 "
	5. Sands of the Lower Calcareous Grit, with concretions and layers of calcareous sandstone. The chief fossils are the small *Exogyra nana* and *Ostrea gregaria* ...	60 "

The upper bed (1) has been largely worked as a building-stone at Headington; but it weathers easily, and is now but little used, except for local purposes.

Strata No. 2 and No. 3 are largely worked for walls and road-metal. In many of the pits the corals are admirably shown, very commonly in the position of growth. The Lower Calcareous Grit is better developed near Cumnor (Bradley farm), where it is extremely rich in entire specimens (in all stages of growth) of *Littorina muricata*, *Cylindrites Luidii*, *Natica clio*, *N. arguta*, *Chemnitzia Heddingtonensis*, *Cerithium muricatum*, *Pleurotomaria bicarinata*, etc. Seeds of Cycadaceous (?) plants are also found in this pit. At Marcham, near Abingdon, this zone is also very fossiliferous, and yields the beautiful well-known calcitic casts of *Ammonites cordatus*, *A. perarmatus*, and other species, which show so admirably the form and arrangement of the chambers. This bed also yields occasionally fine specimens of *Cidaris Smithii* and *Nautilus hexagonus*.

Cambridgeshire. Between the Oxford and the Cambridgeshire district there is a long break; the Corallian strata ending at Wheatley, where the Oxford and Kimmeridge Clays come into immediate juxtaposition. The Corallian strata of the Cambridge district contain an exceptional fauna of Crustacea and various peculiar Mollusca, and a small species of Rhynchonella, etc., together with the characteristic *Cidaris florigemma*.

Yorkshire. The latter local group is again separated from that of the Coralline Oolite of the Yorkshire district, where a distinct and important series of strata of this age are largely developed at Filey, Scarborough, and other places in the interior. The Formation there consists of grits with oolitic and other calcareous strata, and attains a maximum thickness of above 300 feet. It has been carefully described by Phillips, who divided it into—1. Upper Calcareous Grit, with *Belemnites abbreviatus*; 2. Coral-

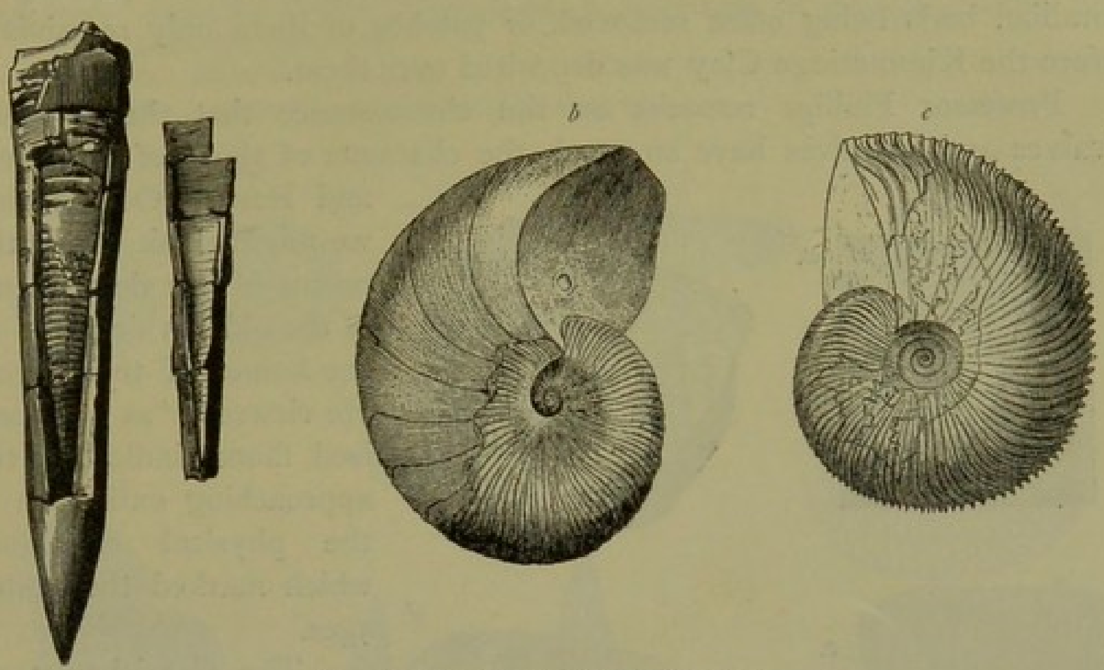

FIG. 118. Cephalopods of the Coralline Oolite.
a. Belemnites abbreviatus, Mill., $\frac{1}{3}$, showing the numerous septa and great length of the phragmacone. *b. Nautilus hexagonus*, Sby. *c. Ammonites excavatus*, Sby.

line Oolite, with *Ammonites vertebralis*; 3. Lower Calcareous Grit, with *Cidaris florigemma* (Pl. VIII, fig. 15). Messrs. Blake and Hudleston introduce a greater number of subdivisions, especially a Middle Calcareous Grit. The following generalised section at Pickering is instructive[1]:—

Upper Division. (Supra-Coralline) Grits and Shales, etc.	
a. An upper grit, with badly preserved fossils	7 feet.
b. Sands and shales, with a basement layer of *Ostrea solitaria*	10 ,,
c. An argillo-calcareous stone ('Throstler')	3 ,,
Middle Division. Upper Limestones.	
d. A false-bedded ferruginous limestone, with *Ostrea*, *Nerinæa*, etc.	5 ,,
e. Impure earthy limestone ('Black Posts'), with few fossils except *Belemnites abbreviatus* and *Ammonites raricostatus*	10 ,,
f. Sub-oolitic limestones, with *Chemnitzia Heddingtonensis*, *Astarte ovata*, *Lucina aliena*, etc.	20 ,,
g. Limestones and pisolites, with *Thamnastræa arachnoides*, *Nerinæa visurgis*, *Perna mytiloides*, *Pecten fibrosus*, etc.	13 ,,
Lower Division (Middle Calcareous Grit in part).	
h. A richly fossiliferous group of calcareous grits and hard blue beds, with *Trigonia perlata*, *Lucina Beanii*, *Cucullæa corallina*, *Gervillia aviculoides*, *Ammonites plicatilis*, etc.	17 ,,
i. Calcareous grits chiefly, with few fossils except *Nautilus hexagonus* and *Ammonites cordatus*	11 ,,

Palæontologically one of the important points connected with the Coralline Oolite is the relation which, when the series is complete, it shows,

[1] *Op. cit.*, p. 335.

on the one hand, with the Oxford Clay below, and, on the other, with the Kimmeridge Clay above; but, on the whole, the relation is more constantly maintained with the former than with the latter; for it is clear that after the deposition of the Corallian strata they were largely denuded (the supra-Corallian beds being often removed, or patches of them only remaining) before the Kimmeridge Clay was deposited over them.

Professor Phillips remarks on the circumstance that the ordinary bivalves and univalves have so much the character of those of the Great and Inferior Oolites that we might think them 'the return of the descendants of the old sea denizens to the homes of their sires.' He viewed it 'as a pauperised fauna, indicating the approaching extinction of the physical conditions which marked the Oolitic ages.'

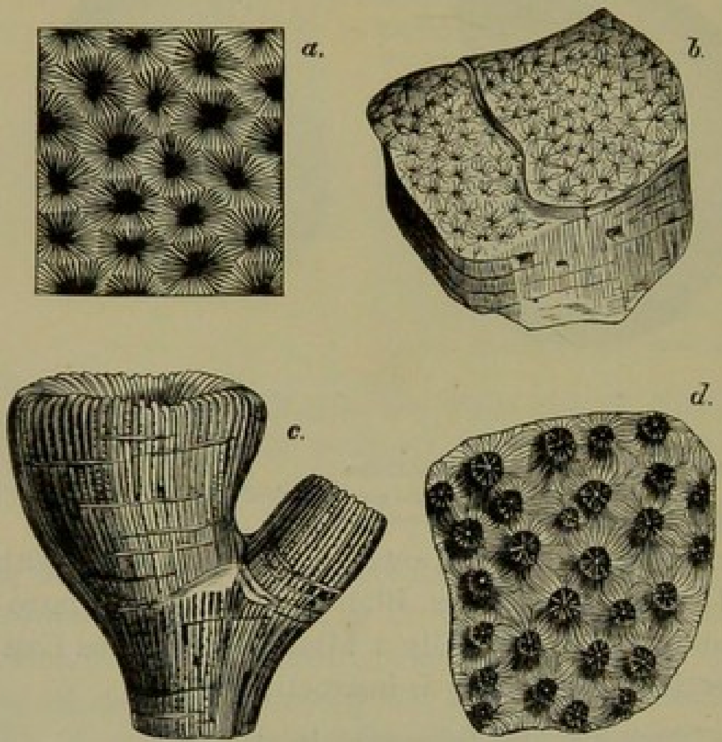

FIG. 119. Corals of the Coralline Oolite.
a. Isastræa explanata, Goldf. *b. Thamnastræa concinna*, Goldf. *c. Thecosmilia annularis*, Flem. *d. Stylina tubulifera*, Phil.

The Coral-banks so characteristic of the middle zone of this series, and to which it owes its name, are never of very great thickness; and the shallowness of the waters in which they were formed is often shown in the perforation of the blocks of Coral by boring Molluscs (*Lithodomus inclusus*). This is the last Formation in the British area in which continuous Coral-banks appear to have flourished. They seem to have extended laterally like the existing Coral-reefs of Florida (see Vol. I. p. 245).

Another group of fossils, often admirably preserved, are the *Echinodermata*. Some remarkably fine specimens, especially of the *Cidaris florigemma*, have been found in the neighbourhood of Calne.

The characteristic fossils of the Coralline Oolite are,—

Plants. Rare: Cycadaceæ and coniferous wood, and fruits probably of Cycads.

Corals. Isastræa explanata, Thecosmilia annularis, Thamnastræa concinna, Montlivaltia dispar, Cladophyllia Conybeari.

Echinoderms. Cidaris florigemma, C. Smithii, Echinobrissus scutatus, Clypeus subulatus, Pygurus costatus.

Annelids. Serpula tricarinata.

Polyzoans and *Brachiopods* are rare. Terebratula insignis.

Bivalve Molluscs. Gervillia aviculoides, Lima læviuscula, Exogyra nana, Ostrea gregaria, Pecten lens, P. vimineus, Cucullæa corallina, Opis corallina, Myacites decurtatus, Trigonia clavellata, T. perlata.

Univalve Molluscs. Chemnitzia Heddingtonensis, Natica arguta, Nerinæa fasciata, Phasianella striata, Pleurotomaria reticulata, Littorina excavata.

Cephalopods. Ammonites cordatus, A perarmatus, A. raricostatus, A. excavatus, Nautilus hexagonus, Belemnites abbreviatus.

Fishes, etc., rare. Hybodus, Pycnodus.

Reptiles, very rare; fragments of Saurian and Chelonian bones.

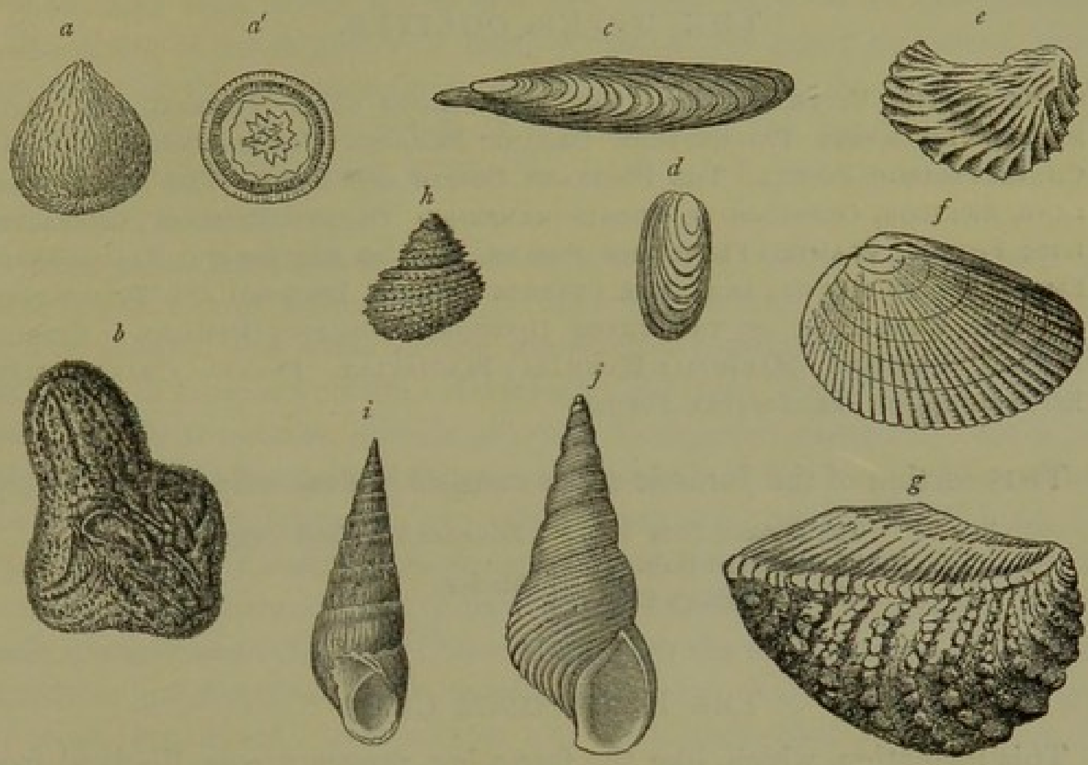

FIG. 120. Other Fossils of the Coralline Oolite.

a. Carpolithus plenus, with section a'. *b. Stellispongia corallina.* *c. Gervillia aviculoides*, Sby. *d. Lithodomus inclusus*, Phil. *e. Ostrea gregaria*, Sby. *f. Lima læviuscula*, Sby. *g. Trigonia clavellata*, Park. *h. Littorina excavata.* *i. Chemnitzia Heddingtonensis*, Sby. *j. Phasianella striata*, Sby.

The land and shallow clear seas now underwent a subsidence, whereby the seas became deepened; argillaceous sediments succeeded to the calcareous deposits; and, to the Coral-banks and littoral conditions of the Corallian, followed the deeper-sea fauna of Cephalopods and huge Enaliosaurians of the Kimmeridge period.

CHAPTER XV.

THE UPPER OOLITES.

Divisions of the Upper Oolites. The Kimmeridge Clay. Mineral Oil. Alum Shales. Thickness. Passage-beds. Organic Remains. Plesiosaurus. Iguanodon. Characteristic Fossils. The Portland Oolite and Sands. The Isle of Portland, Swindon, Oxfordshire, Buckinghamshire. Organic Remains. Characteristic Fossils. Plants. Fluviatile Shells. End of the Oolitic Marine Series. Emergence of the Sea-bed. The Purbeck Strata. Dirt-bed and Forest-trees. General Character of the three Divisions. Organic Remains. Cypridæ. Insects. Reptiles. Marsupial Mammals; Plagiaulax. Plants. Characteristic Estuarine and Fresh-water Fossils.

THIS section of the Jurassic series consists in descending order of—

The Purbeck Beds .	Estuarine and Fresh-water.
The Portland Beds .	Marine.
The Kimmeridge Clay .	

The Kimmeridge Clay.

This formation, which, like the foregoing, ranges across England from the coast of Dorsetshire to that of Yorkshire, derives its name from the village of Kimmeridge, in the Isle of Purbeck, where it forms a high cliff-section. It consists of dark-blue clays, with septaria, bands of argillaceous limestones, and occasional lignite seams. It contains also subordinate seams of fine paper-shales, and, in places, bituminous shales that are sometimes locally used for fuel, and have been used for the manufacture of gas. Volatile and mineral oils and mineral pitch are also to be obtained from it by distillation at a low temperature[1]. Alum works formerly existed at Kimmeridge. In the Boulonnais the septaria make an excellent hydraulic cement; at Weymouth, they are cut and polished for table-slabs.

Iron-pyrites is widely dispersed through the clay and shales, and its decomposition led a few years ago to the spontaneous combustion of the strata in a cliff near Weymouth, where the fire smouldered for several years. In some of the clay beds, small crystals of selenite are common. They are plentiful in the lower beds near Oxford.

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[1] An account of these and of the so-called 'Coal-money' will be found in Damon's 'Geology of Weymouth,' edit. of 1884, pp. 56–63, and 76.

In Dorsetshire the Kimmeridge Clay is about 600 feet thick. It thins off to about 100 feet in Oxfordshire, but swells out again as it ranges north, attaining a thickness of above 400 feet in Lincolnshire. Professor Blake[1] considers that the beds in the different parts of its range are not synchronous, but that they represent different zones, which, if put into superposition, would give a total thickness of 1050 feet or more[2]. He further states that the Kimmeridge clay should be divided into an upper and lower division, and that, when it overlies the upper division of the Coralline Oolite, there is occasionally a local series, of no great thickness, which may be called the Kimmeridge passage-beds. The upper division is more largely developed in the South of England, and the lower in the north, where it consists of a mass of blue or sandy clay, with great ferruginous boulder-like concretions.

Organic Remains. There is a marked distinction between the fossils of the Lower Kimmeridge of Lincolnshire and the Upper Kimmeridge of Dorset. In some of the intermediate districts, the relative age of the beds is more uncertain. *Ammonites Berryeri*, *Rostellaria Rasenensis*, *Cerithium forticostatum*, *Nucula Merkii*, *Inoceramus expansus*, *Ostrea deltoidea*, *Lagena apiculata*, are characteristic fossils of the Lower Kimmeridge both in Dorset and Lincolnshire; while *Ammonites biplex* (Pl. VII, fig. 10), *Gryphæa virgula*, *Cardium striatulum*, *Lingula ovalis*, and *Discina latissima* are everywhere characteristic of the Upper Kimmeridge. Judging by the fossils, it would seem that near Oxford, although the Kimmeridge Clay is only from 80 to 100 feet thick, both divisions exist, but that the upper division is the more important. Ammonites are both numerous (31 species) and characteristic. The singular fossil, *Trigonellites* or *Aptychus* (*A. latus*), which is now known to be a peculiar appendage (the operculum) of some species of Ammonites, is common in the Kimmeridge Clay.

The great Saurians appear to be the most numerous in the upper division of the Kimmeridge formation. The *Pliosaurus brachydeirus* is common to both divisions. The Pliosaurus makes its first appearance in the Oxford Clay, but the Kimmeridge Clay is its great home. It was a swimming reptile of gigantic size, having Plesiosaurian affinities in the general form of the vertebræ and structure of the paddles, and Ichthyosaurian in the form and size of the head, so that it combined the powerful swimming apparatus of the former with the gigantic jaws and large teeth of the latter. An imperfect head in the Oxford Museum is seven feet long, and another in the Dorchester Museum measures seven feet six inches in length. In the same Museum there is a tooth nearly a foot in length. The fang is very long compared with the crown, which is marked by two strong ridges passing

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[1] 'Quart. Journ. Geol. Soc.' vol. xxxi. p. 196, 1875.

[2] At the Battle or Nettlefield boring in Sussex, the Kimmeridge Clay was found to be about 1070 feet thick.

down the apex and dividing it into unequal spaces. There is also at Dorchester a paddle six feet nine inches long. These measurements will give some idea of the great Enaliosaurian designated by Owen 'the tyrant of the Oolitic Seas.'

The recent discovery of a new species of Iguanodon[1] (*I. Prestwichi*), a young individual, 10 to 12 feet long, and nearly entire, in the Upper Kimmeridge Clay at Cumnor, near Oxford, is interesting, as this genus had not before been met with in strata older than the Wealden.

The total of all the organic remains recorded by Professor Blake is 278, amongst which are thirty-two Foraminifera, six Entomostraca, two Cirrhipedia, twelve Echinodermata, two Crustacea, four Annelida, seven Brachiopoda, a hundred and sixty Mollusca, sixteen Fishes, forty-one Reptiles, and one Coniferous fruit. There is only one Coral.

The following are the more common species :—

Plants.—Coniferous Wood.

Brachiopods.—Lingula ovalis, Rhynchonella inconstans.

Bivalve Molluscs.—Astarte ovata, Cardium striatulum, Lucina minuscula, Pholadomya æqualis, Thracia depressa, Gryphæa virgula, Ostrea deltoidea, Pecten lens, Trigonia Pellati, T. Voltzii.

Univalve Molluscs.—Pleurotomaria reticulata, Littorina muricata.

Cephalopods.—Ammonites biplex, A. serratus, A. decipiens, Belemnites Blainvillei, B. nitidus, Aptychus latus.

Fishes.—Asteracanthus ornatissimus, Gyrodus coccoderma.

Reptiles.—Ichthyosaurus trigonus, Plesiosaurus brachyspondylus, Pliosaurus grandis.

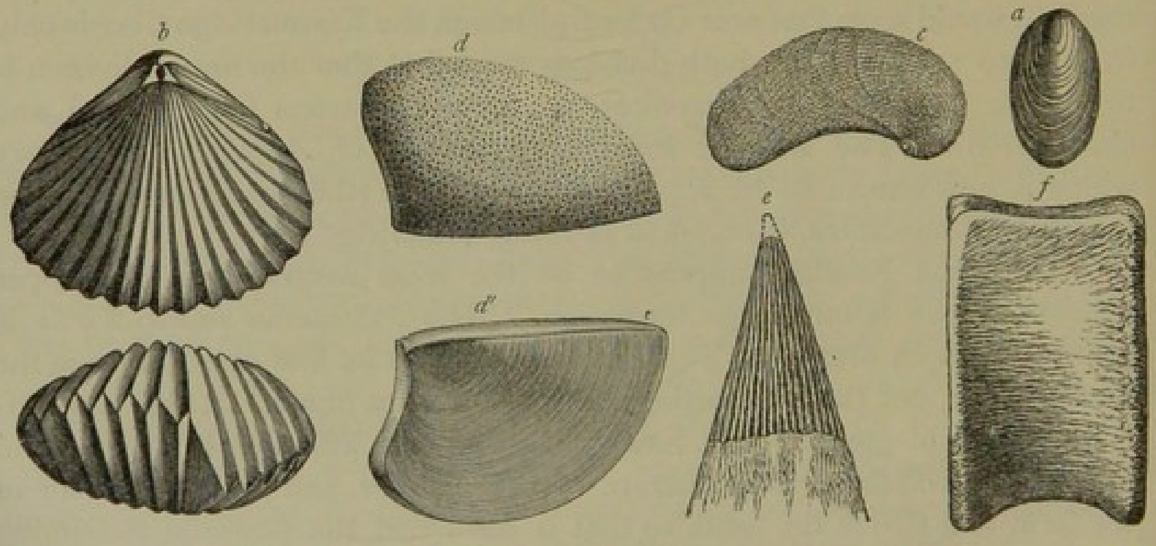

FIG. 121. Fossils of the Kimmeridge Clay.
a. Lingula ovalis, Sby. *b. Rhynchonella inconstans*, Sby. *c. Gryphæa virgula*, Defr. *d. Aptychus sublævis ; outside ; d'. inside. e. Tooth of Ichthyosaurus. f. Side view of dorsal vertebra of Pliosaurus macromerus*, Phil.

Professor Blake remarks that Corallian species are almost entirely confined to the passage-beds, and that the true Kimmeridge Clay has very little community of fauna with that formation.

[1] Described by Mr. Hulke in 'Quart. Journ. Geol. Soc.' vol. xxxvi. p. 433.

THE PORTLAND BEDS.

Overlying the Kimmeridge Clay is a series of sands, sometimes glauconiferous, with concretionary sandstones and clays, succeeded by massive oolites and freestones, forming the series known as the Portland Beds. These strata are the lowest of those described by Dr. Fitton in his great paper 'On the Strata below the Chalk[1].' Mr. Damon has given a description of the series in the Weymouth district[2], and Professor Blake has more recently given a detailed account of the Portland beds of England and of their relation to their equivalents in the Boulonnais[3].

The fine natural sections of the Isle of Portland exhibit the series from its base up to the Purbeck beds by which they are capped. That section is as follows :—

Section of the Portland Beds of the Isle of Portland.

	ft.	in.
1. Roach—a shelly and cherty light-coloured limestone of variable thickness, full of casts and impressions of shells—*Cerithium Portlandicum*, *Trigonia gibbosa*, *Lucina Portlandica*, etc.	3	6
2. Whit-bed—a hard, fine-grained, whitish, calcareous, and oolitic freestone with *Ammonites giganteus*. This yields the best building stone	8	6
3. Base-bed—a soft, white, calcareous freestone, with a thin subordinate bed called 'Curf,' containing a seam of corals (*Isastræa oblonga* perforated with *Lithodomi*) and oysters (*Ostrea solitaria*)	8	6
4. Impure white limestone (not worked), with layers of black cherty flint—*Trigonia gibbosa*, *Perna mytiloides*, *Serpula gordialis*, *Ostrea multiformis*, *Ammonites Boloniensis*, *A. triplex*, etc.	40	0
5. Unfossiliferous blue Marl	12	0
6. Marly Sands, with concretionary nodules—*Mytilus Autissiodorensis*, *Pecten solidus*, *Cyprina elongata*, etc.	26	0
7. Compact bed of *Exogyra Bruntrutana*	7	0
8. Yellow sands with *Cyprina uniplicata*	10	0
9. Sandy marl with *Lima Boloniensis*, *Pecten Morini*, *Trigonia incurva*, etc., resting on the Kimmeridge Clay	30	0

There is a fine exposure of the Portland rock, with a great development of the lower sands, estimated by Professor Blake at 244 feet, on the coast at St. Alban's Head, Dorset. At Upway, north of Weymouth, the section is small, but instructive. Some of the beds, with black flints, are white and soft, and closely resemble chalk.

The Portland Oolite appears again at Tisbury, in the Vale of Wardour. Local features of interest are the fine chalcedonic masses of Coral (*Isastræa oblonga*) showing structure. Trigonia and other shells also occur there fossilised in the state of siliceous casts.

Some lower beds at Tisbury, having a peculiar group of shells, Professor Blake considers may be local passage-beds from the Kimmeridge Clay.

[1] 'Trans. Geol. Society,' 2nd Series, vol. iv. p. 103, 1836.
[2] 'Handbook to the Geology of Weymouth,' 1860.
[3] 'Quart. Journ. Geol. Soc.' vol. xxxvi. p. 189, 1880.

Amongst these shells are *Mytilus Jurensis*, *Exogyra Bruntrutana*, *Trigonia Pellati*, etc.

The Portland beds of Swindon are interesting from showing their relation to the overlying Purbecks; while the Portland Sands (at the base) there contain a well-marked and somewhat peculiar fauna, among which are *Ammonites pectinatus*, *Turbo Foucardi*, *Pholadomya tumida*, *Astarte polymorpha*, *Perna Bouchardi*, etc.

In Oxfordshire the sand beds only exist. They contain at Shotover large blocks of a concretionary calcareous sandstone, in which the *Perna mytiloides*, *Cardium dissimile*, *Trigonia gibbosa*, *Ammonites pectinatus*, etc. are found. In this district the whole Portland series is reduced to about sixty feet in thickness.

At Brill there is a white, marly limestone, containing *Cardium dissimile*, *Perna mytiloides*, *Trigonia gibbosa*, etc., together with a remarkable bed of *Ostrea expansa*, in which the shells are double and in a very perfect state of preservation.

At Hartwell, where these rocks make their last appearance northward, the upper beds are greatly eroded, and the rock has no longer an oolitic character, but consists of a shelly brash with an abundance of *Trigonia* and *Ammonites*. Some of the beds are thickly perforated by *Lithodomi*.

Organic Remains. These consist of 146 species, consisting of one Coral, three Echinoderms, two Annelids, one Crustacean, a hundred and thirty-two Mollusca, three Fishes, and four Reptiles.

A few scarce plant-remains have been found in the Portland beds of Portland. Mr. G. Clifton showed me in his collection at Government House the impression of a Fern from the freestone, and a fine Cycad (*Mantellia*) in chert from the 'Roach Rock,' while about 48 feet below the top of the 'Roach' he found (bed No. 4, p. 229) the fossilised trunk of a tree encircled by a deposit of flint more than an inch thick.

Colossal specimens of *Ammonites giganteus*, some exceeding four feet in diameter, are found in Portland; and the numerous casts of *Cerithium Portlandicum*, known by the workmen as the 'Screw,' give a peculiar aspect to the Roach Rock.

In the Isle of Purbeck a bed, formed by a mass of the shells of the *Ostrea solitaria*, eight feet thick, overlies the freestone.

Professor Owen has described a species of *Pliosaurus* (*P. Portlandicus*) from the Portland beds. It is inferior in size to the great *Pliosaurus* of the Kimmeridge Clay.

The characteristic fossils of the Portland limestones are,—

Corals.—Isastræa oblonga.

Bivalve Molluscs.—Ostrea solitaria, O. expansa, Cardium dissimile, Perna mytiloides, P. Bouchardi, Pecten lamellosus, Lucina Portlandica, Lima rustica, Myacites Jurassi, Cytherea rugosa, Trigonia gibbosa, T. incurva.

Univalve Molluscs.—Cerithium Portlandicum, Natica elegans, Pleurotomaria rugata, Neritina sinuosa.

Cephalopods.—Ammonites giganteus, A. Boloniensis, A. triplicatus, A. biplex, A. pectinatus.

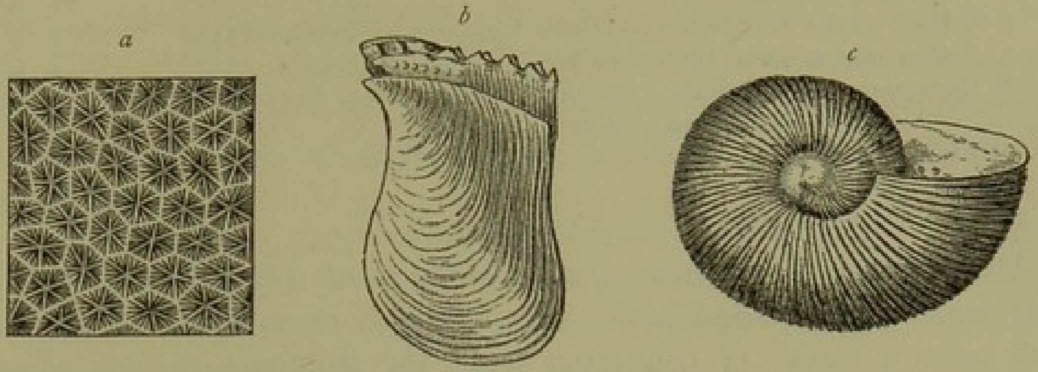

FIG. 122. Fossils of the Portland Oolite.
a. *Isastræa oblonga*, Flem. b. *Perna mytiloides*, Lam. c. *Ammonites pectinatus*, Phil.

With the Portland rocks ends the long series of marine strata of Oolitic times. There have not been wanting during this period indications of the near proximity of land, such as shown by the numerous remains of plants in many strata, by the Dinosaurs of the Stonesfield beds and the Forest-marble, by the small Stonesfield Mammals, by the cycadaceous fruits in the Corallian rocks, by the Iguanodon of the Kimmeridge Clay, and by the frequent fragments of drifted wood; nor, as just mentioned, are plant-remains entirely wanting in the marine beds of Portland.

There are also both in Lincolnshire and in Oxfordshire traces of a river-shell (*Cyrena*) in some intercalated marls, but they are too imperfect for exact determination.

With the next succeeding stage we pass, in England, into a deposit which contains a land fauna and flora of a more definite character; for the Portland period was brought to a close by the elevation of the sea-bed, which was thereby converted into an area of dry land, with its lakes and rivers, forests, and its many small mammals. Notwithstanding these differences of conditions, there is evidently a close relation between the Portland and the Purbeck beds.

THE PURBECK STRATA.

These strata, as their name implies, are best developed in the Isle of Purbeck, where they have been quarried for ages. They were first described by Buckland and De la Beche[1], again in greater detail by Fitton[2], and since then by other observers presently to be referred to.

Only the lower beds of the Purbecks are met with at Portland; still the sections are of much interest, as the 'dirt-bed' is frequently uncovered and the old land-surface is thus exposed.

[1] Trans. Geol. Soc. 2nd Ser., vol. iv. p. 1.
[2] Ibid. p. 103.

Section in one of the Portland Quarries (after Fitton[1]):—

	ft.	in.
1. Vegetable soil	1	0
2. Light-coloured fissile Limestone (called 'slate') with Cypridea and a small bivalve shell	10	0
3–6. Dark clays ('Dirt-beds') and fissile limestones with seams of sand ...	4	4
7. Soft calcareous stone ('Soft-burn')	2	6
8. Carbonaceous loam (main '*Dirt-bed*') with Cycadeæ, fragments of stone ('gravel'), and stumps of trees	1	0
9. Light drab-coloured limestone, spongy in places ('cap')	8	0
10–12. Same as 8 and 9	2	6
13. The Portland Rocks.		

Dr. Fitton remarks that stratum No. 9 much resembles a fresh-water travertine. The dirt-bed is the vegetable soil of an old land-surface, on which grew a forest of coniferous trees, the stumps and roots of which remain in the position of growth, while the trunks (occasionally with a few remaining branches) are broken off and lie alongside. These old stems are sometimes from twenty to thirty feet long, and instances are mentioned where they attained a length of sixty feet. The undergrowth of this old forest consisted of species of Cycadaceæ (*Mantellia megalophylla* and *microphylla*), a family of plants now chiefly restricted to the tropical and temperate regions of America and Asia. Both these and the trees, which are related to the recent *Araucaria*, are silicified, the structure of the wood being well preserved, and the annual rings of growth distinct.

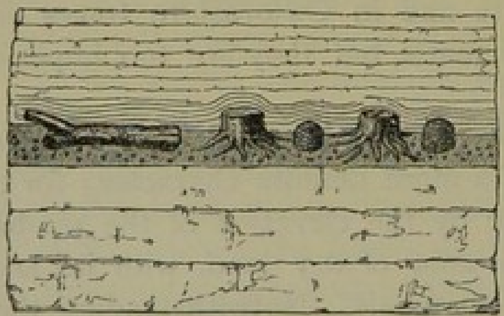
Fig. 123. *Section of the Dirt-bed, Isle of Portland.*

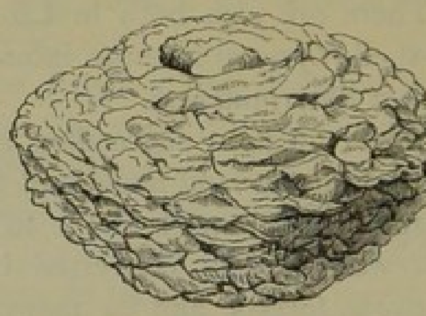
Fig. 124. *Mantellia megalophylla*, Bronn.

The series is much more complete at Lulworth, Swanage, and Ridgeway, where the beds have been described in great detail by Edward Forbes, H. W. Bristow[2], and the Rev. Osmond Fisher[3]. They have been divided into three groups, consisting of some 160 beds, with a maximum thickness of 330 feet; though they usually do not exceed 150 to 200 feet.

	ft.	in.
1. Upper Purbecks, with fresh-water limestones	59	0
2. Middle Purbecks, with estuarine and marine shells, and numerous fish-remains	130	0
3. Lower Purbecks, with estuarine and fluviatile remains and two dirt-beds (surface-soil) near its base	140	0

[1] *Op. cit.* p. 219. [2] Sections of the Geological Survey.
[3] 'Trans. Cambridge Phil. Soc.' vol. ix.

The 'dirt-beds' at Lulworth have been tilted, and now incline at an angle of nearly 45° with the horizon.

The lower division of the Purbecks consists of a series of marly limestones, alternating with thin clays, and containing a few seams of chert. This division abounds with *Cyprideæ*, and fresh-water shells of the genera *Paludina*, *Rissoa*, and *Cyclas*. It also contains scales of Fishes; and one thin band is full of the fragments of an Isopod Crustacean, the *Archæoniscus*.

Another stratum contains a very interesting series of Insect remains. The upper beds of this lower division show indications of brackish water conditions by the presence of *Cardium*, *Serpula*, and *Corbula*. Some of the beds are ripple-marked.

The middle division consists of shales, with layers of hard limestones. This division differs from the others inasmuch as it contains more intercalated marine beds, one of the lower of which, known as the 'cinder bed,' about four feet thick, is composed almost entirely of a mass of small Oyster shells, the *Ostrea distorta*.

There are also in this division well-known beds consisting of fibrous carbonate of lime, called by the quarrymen 'Beef.'

The remains of Turtles are also found; but the most interesting of the fossils of this division are the Mammalian remains of which we shall presently speak.

The upper division consists of shelly argillaceous limestones, shales, and clays, containing *Uniones*. Some of the limestones are full of a small *Paludina*, forming an ornamental stone, largely worked in former times for shafts of pillars and slabs of tombs in churches, and known as the 'Purbeck Marble.' This division also contains numerous fresh-water shells of the genera *Paludina*, *Limnæa*, *Cyclas*, *Unio*, and *Physa*, with scales and teeth of Fishes, and the remains of Turtles.

In the Purbeck series, alum shales, pseudomorphic crystals of rock-salt, and crystals and seams of gypsum or alabaster are occasionally met with. In the great trial-boring near Battle, in Sussex, a deposit of gypsum, or rather of alabaster, as much as thirty feet thick, was found in the lower part of the Purbeck series.

Purbeck beds again cap the Portland strata at Swindon[1]; they appear in diminished force at Shotover Hill and Hazeley near Oxford, and on the top of Brill Hill. They are finally lost in the neighbourhood of Aylesbury.

Organic Remains. These are far from numerous, the total of all classes, exclusive of insects, not exceeding about 100 species. The mollusca are limited to very few genera, the principal being *Cyclas*, *Cyrena*, *Paludina*, *Unio*, and *Rissoa*, but the individuals occur in vast abundance.

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[1] Blake, *Op. cit.* p. 205.

Of the Crustacea the small Entomostraca are extremely plentiful and characteristic. Edward Forbes found that each of these divisions of the Purbeck had a peculiar group of Cypridæ, the lower beds being characterised by the prevalence of smooth species, such as the *Cypris Purbeckensis*; the middle beds by a tuberculated species, *Cypridea fasciculata*, and the upper beds by a pitted form, *C. punctata*.

In the Purbecks of the Vale of Wardour, and occasionally at Durdlestone Bay (Swanage), a peculiar fresh-water Isopod Crustacean occurs in an admirable state of preservation—the *Archæoniscus Brodiei*. Like the Trilobites of the Palæozoic series, this small Crustacean was gregarious and occurs in thousands. On one small slab of stone (6 × 9 inches) more than fifty specimens have been counted. Its distribution is very local. (See fig. 126.)

The Insects of the Purbeck series have been described by Professor Westwood. In the Purbeck strata of the Vale of Wardour he determined

FIG. 125. Purbeck Insects, nat. size. (After Brodie.)
a. *Carabus elongatus*, Brod. b. *Elytron of one of the Tenebrionidæ.* c. *Cixius* (?) *maculatus*, Brod. d. *Acheta Sedgwicki*, Brod. e. *Platyura* (?) *Fittoni*, Brod. f. *One of the Chironomi.* g. *Larva of a sub-aquatic dipterous Insect.* h. *Blatta Stricklandi*, Brod. i. *Ricania* (?) *fulgens*, Brod.

the existence of Beetles allied to the recent *Carabus*, *Cerylon*, *Colymbetes*, *Elater*, *Buprestis*, etc., of Dipterous Insects allied to *Simulium*, *Ryphus*, *Culex*, etc., of *Libellulidæ*, and some others, amounting altogether to nearly a hundred species.

With regard to the characters and inferences to be drawn from these Insects, I cannot do better than quote the Professor's own words :—'The minute size of very many of these specimens, especially amongst the Diptera and Coleoptera, will not fail to be noticed, and this remark is of importance . . . . . as it is well known that the lower the temperature the smaller the Insects which inhabit that particular region. At the same time, there are certain individuals which, judging from present insect-life, must have been inhabitants of a warm if not a tropical climate, as for instance the Ricania, etc. With these trifling exceptions, there seems nothing to warrant the supposition that these insects were inhabitants of a climate very different from that of our own country. . . . . The little Aphis is an especial proof of the correctness of this opinion; because in the present day there are no Aphides in the tropics, their place being occupied by much larger insects, which are consequently able to perform the part of Aphides in nature in a more effectual manner. These are the Cuckoo-spit Insects, of which our *Cercopis spumaria* is a smaller type. We find, moreover, the minute Curculionidæ (vegetable feeders),—Silvanus (?) (xylophagous, or rather feeders on dry seeds, meal, etc.),—vast numbers of minute Tipulidæ of various genera (for the most part inhabitants of moist or wet situations),—the terrestrial Cricket and omnivorous Cockroach,—the plant-sucking Aphides and Delphax,—Cuckoo-spit Insects (Cercopidæ and Cicadellinæ),—and Dragon-flies, inhabitants of the water in their first and of the air in their last state, some of a gigantic size,—with wings of Insects nearly allied to the almost equally voracious insect-feeding genera Panorpidæ[1].'

Subsequently Westwood, speaking of the Insect remains from the Purbecks of Ridgeway and Durdlestone Bay, Dorset, remarks:—'With the exception of the winged giant Ants, and of some of the fragments of gigantic Dragon-flies' wings, there seems to be . . . . a general conformity with the Purbeck insects of Wilts[2]. . . . . But, if the general conditions of insect-life were so similar in the two districts, as indicated by the remains in the Wilts and Dorset Purbeck formations, the mode of destruction of such insect-life must have been very different, since we found abundance of specimens of insects in a tolerably entire state of preservation in the former, whilst in the latter scarcely anything but fragments of wings or elytra, or a few segments of the abdomen, occur.

'If we take into consideration the small and even minute size of the great majority of the insects, and indeed of the whole of the *Coleoptera*, which have been passed under review, the idea that we have before us the wreck of an Insect Fauna of a temperate region is at once raised; for although it would be rash to assert that a mass of remains of the existing tropical insects might not be accumulated in which a large quantity of minute beetles and flies would not be present, yet I cannot conceive any process, either arising from currents of water or chemical dissolution of insect matter, which would carry off or destroy the many gigantic forms of insect-life always occurring in the tropics.

'The fossils before us show abundant evidence of the presence of numbers of Lignivorous species, such as the *Elateridæ* and *Buprestidæ*; but we nowhere find amongst them traces of the great Lamellicorn and Longicorn beetles. Herbivorous insects also occur in considerable numbers, but we do not meet with the gigantic Grasshoppers and Locusts of tropical climates. . . . . I must leave geologists to discover or to suggest the

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[1] Brodie's 'Fossil Insects,' Introd. p. xi; 1845. Westwood speaks of these Vale of Wardour specimens as *Wealden* Insects, as at that time the Purbecks were considered to form the base of the Wealden.

[2] 'The discovery of closely allied fossil Isopoda in both the localities is especially to be noticed.' Quart. Journ. Geol. Soc. vol. x. p. 392. The giant Ant, however, here referred to is a Tertiary specimen, inadvertently included in the list.

action which could have brought together and deposited such great masses of insect-remains as we find in many of the slabs of stone. . . . . Entomologists, however, are perfectly well aware that sudden inundations or the rapid rising of rivers are sure to bring with them the most abundant entomological harvest, insects being floated down such currents in vast numbers, and congregated together in masses on the banks, as thick as bees in a hive or ants in an ant-hill.'

Only one species of Echinoderm has been found in the Purbeck, the *Hemicidaris Purbeckensis.*

The remains of Fishes are widely dispersed, but they consist chiefly of scales, teeth, and palates. The principal species are:—*Aspidorhynchus Fisheri*, *Lepidotus Mantelli*, *Histionotus angularis*, *Pholidophorus ornatus.*

Of Reptilian remains those of Turtles, of which some very fine and perfect specimens have been found, such as *Chelone obovata* and *Pleurosternum emarginatum*, are the most numerous. Remains of Crocodilian reptiles (*Goniopholis crassidens* and others) are not unfrequently met with. The most curious of such remains are some described by Sir Richard Owen[1], from the Purbecks of Dorset. They are those of two species of dwarf Crocodiles (*Theriosuchus pusillus* and *Mammosuchus gracilidens*). He estimates the average length of a mature *Theriosuchus*, which in some respects approaches the type of the broad-faced Alligators, at 18 inches, and the length of the skull at 3½ inches, and suggests the possibility of a relation between these small Mesozoic Crocodilia and the cotemporary diminutive Mammals on which they may have fed, and which would have little availed the larger Crocodiles of the character of those of the present day. Professor Owen has also described two Pleurodont Lizards from the Purbeck Beds, the one a carnivorous or insectivorous Lizard (*Nuthetes*) of the size of the great Land-Monitor of India, and the other a smaller species, which he has termed *Macellodus Brodiei.*

But the most remarkable of all the organic remains of the Purbeck series are those of the small Marsupial Mammalia. Some specimens were discovered by Mr. W. R. Brodie, in 1854, in a thin, probably lacustrine, marl, at the base of the middle Purbecks in the cliff at Durleston Bay near Swanage. Subsequently he found some more.

Following up this clue, Mr. S. H. Beckles, F.R.S., devoted some months to the exploration of this bed, and was rewarded by the discovery of a number of similar remains. Like those already described from the Triassic and Oolitic strata, they were those of small marsupials; and, with very few exceptions, the remains consisted of lower jaws only. The first discovered was a little insectivorous marsupial, the *Spalacotherium*

[1] 'Quart. Journ. Geol. Soc.' vol. xxxv. p. 148.

tricuspidens, about the size of a squirrel. Subsequently Dr. Falconer determined the existence of two other and rather larger species, the *Plagiaulax Becklesii* and the *Plagiaulax minor*. The dentition of these two little animals presents very puzzling peculiarities. The incisors are long and pointed, while the molars present a trenchant crown traversed by diagonal furrows.

Dr. Falconer pointed out that in this and some other characters the creature was allied to the living *Hypsiprymnus Gaimardi*, or Kangaroo-rat of Australia, a small nocturnal animal, living in woods and feeding on plants. Sir Richard Owen, on the contrary, considers that the animal was carnivorous.

Owen[1] has determined Mr. Beckles' specimens to belong to no less than twenty-five species (including the previous three), referable to eleven genera, the most abundant being *Stylodon*, *Triconodon*, and *Plagiaulax*. Most of them, with the exception of *Plagiaulax*, have cuspidate teeth, generally sharply pointed, such as characterise insectivorous animals. They are all small, the largest being about the size of the native rat of Australia.

Owen, reviewing the evidence of the mammalian remains from the Mesozoic series generally, remarks that the life of that period 'is, without

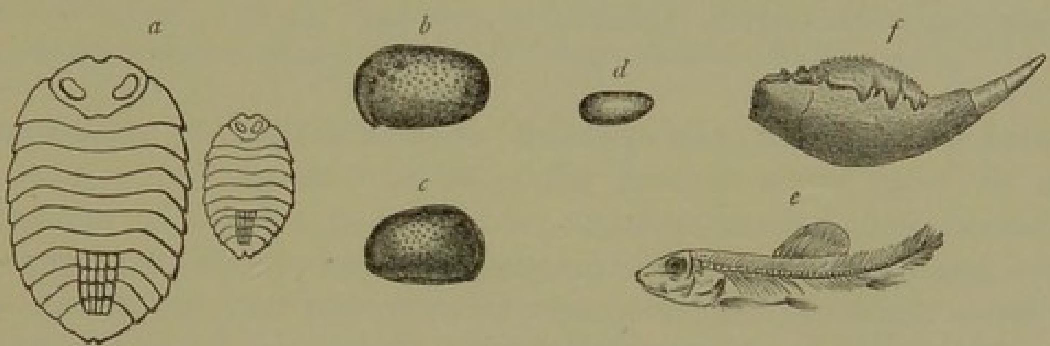

FIG. 126. Purbeck Fossils.

a. Archæoniscus Brodiei, M. Edw. *b. Cypridea granulosa* (Sowerby), $\frac{12}{1}$. *c. Cypridea punctata* (E. Forbes), $\frac{12}{1}$. *d. Darwinula leguminella* (E. Forbes), $\frac{15}{1}$. *e. Leptolepis Brodiei*, Eg. *f. Jaw of Plagiaulax minor*, Falc., nat. size.

exception, low, insignificant in size and power, adapted for insect food, for preying upon small lizards, or on the smaller and weaker members of their own low mammalian grade' (p. 111).

The Purbeck series contains few plant-remains except Cycadaceæ and Conifers. Dr. Fitton mentions the occurrence of a species of *Damarites*, a conifer allied to the Araucarian pines of India. In some of the beds small seeds of the *Chara*, a fresh-water plant of a genus living at the present time in our ponds and lakes, have been discovered in great abundance.

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[1] 'Monograph Palæontographical Soc.' for 1870.

The following are some of the characteristic Purbeck fossils:—

Plants.—Mantellia (Cycadeoidea) megalophylla.

Crustacea.—Archæoniscus Brodiei, Cypris Purbeckensis.

Fresh-water Mollusca.—Cyrena media, Anodonta Purbeckensis, Melanopsis harpæformis, Paludina elongata, Physa Bristovii.

Marine Mollusca.—Ostrea distorta, Pecten Purbeckensis, Corbula alata, with species of Cardium, Modiola, etc.

Mammalia.—Plagiaulax Becklesii, Triconodon ferox, Stylodon pusillus, Bolodon crassidens.

With the Purbeck ends the series of Oolitic strata. The next and uppermost division of the Mesozoic strata is the Cretaceous, the lowest member of which is the Wealden.

CHAPTER XVI.

THE FOREIGN EQUIVALENTS OF THE JURASSIC SERIES.

Absence of Great Disturbances during the Jurassic Period. A Period of Slow Changes. The Jura Mountains. The Range of the Lias. The Lias of the Salinois; of France and Belgium. The French Divisions. Central Europe and Italy. The Lias of Germany. Table showing the range of the Ammonite-Zones in Europe. The Upper Jura or Oolitic Series. France; The Bas-Boulonnais; Normandy; Poitou; The Ardennes; Lorraine; Burgundy. The Lias of the Swiss Jura; of Germany—South and North. The Solenhofen Beds of Bavaria. Russia. The Alps, Italy, South Austria, and Spain. North and South America. India. Australia. New Zealand. South Africa.

Absence of Disturbances during the Jurassic Period. The structure and organic remains of the Jurassic strata show on the Continent, as in England, that they were deposited during a long period of comparative calm and repose, which succeeded to the prolonged and wide-spread disturbances that had prevailed over great part of the old world at the Permian and Triassic periods. Nevertheless steady and long-continued slow movements, either of subsidence or of elevation, were going on throughout Europe during the whole of the Jurassic period; but, although there were depressions of the land and elevations of the sea-bed, the oscillations were in great measure confined to the area occupied by the Jurassic seas and the lands immediately surrounding them,—the waters alternately advancing and retreating, and the seas becoming deeper or shallower according as the land rose or sunk. Consequently, the several divisions of the Jurassic series exhibit, in the many alternations of deep-water argillaceous strata and of shallow-water calcareous shell-sands and coral-banks, the results of those varying conditions of depth and deposition. Towards, however, the end of the Jurassic period pelagic conditions prevailed over the Alpine area and southern Europe; and therefore in that area the whole of the more or less shallow-water and estuarine strata (those from the base of the Kimmeridge to the top of the Purbeck) are represented by a single group (the Tithonian), with a fauna of peculiar Cephalopods and Brachiopods.

During the Jurassic period there was an entire absence of the more rapid rending, fracturing, and ridging of the earth's crust, so frequent during the preceding periods, and no great mountain-chains were formed. Everything, on the contrary, denotes slow and quiet change—changes so slow as to cause little destruction to the existing life, and yet sufficiently important to introduce from time to time new conditions involving temporary oceanic changes; but these were sooner or later always followed by the recurrence of previously existing conditions, and favourable to the continued existence of the same generic forms of life. Consequently the fauna of the Jurassic period presents throughout, in its Echinodermata, its varied Mollusca, its innumerable and special Cephalopoda, its teeming Fishes and huge Saurians, a similarity of type and a vigour of life compatible with a period of comparative repose.

The Jura Mountains. This range, which has given its name to the series, furnishes for continental Europe the type of the Jurassic system. It there consists of two great divisions—a lower group of argillaceous, arenaceous, and calcareous strata, constituting the Liassic series, and an upper calcareous series constituting the division of the Oolites. The broad divisions are perfectly analogous to those in this country, but the minor subdivisions present numerous local variations, both petrologically and palæontologically. All these strata are successively brought to the surface in the several powerful flexures which, at a later period, raised the Jura, and run parallel with the axis of the Alps. The lower, or Liassic division, is best developed in the Western or French Jura, where it has been described, together with the Trias and the Oolitic series, by M. Jules Marcou[1]; while the latter forms the greater part of the Eastern or Swiss Jura, and has been described by M. Jaccard[2] and others.

The Range of the Lias. The divisions of the Lias adopted in this country hold good generally throughout Europe, although there is a diversity of opinion with reference to the grouping of the lower or *Ammonites angulatus* and *A. planorbis* zones. Some geologists group these zones in the Lower Lias or Sinemurian; others, on the contrary, have, as before mentioned, grouped them under the term Hettangian in a fourth subdivision. It is true that it is often difficult to draw a line of separation between the *Ammonites Bucklandi* and *A. angulatus* zones, but on the whole, and especially in the north-east of France, the Hettangian forms a well-marked and distinct subdivision, with a large fauna of above 200

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1 'Recherches sur le Jura Salinois'; Mém. Soc. Géol. de France, 2e Sér. vol. iii. p. 1.

2 'Description géologique du Jura Neufchâtelois et Vaudois'; Explic. de la Carte Géol. de Suisse. See also the works of MM. Desor, Gressly, Thurmann, and De Lauriol.

species, many of which are peculiar to it. Amongst the characteristic fossils, besides the two Ammonites, are *Montlivaltia Haimei*, *M. Guettardi*, *Ostrea Hisingeri*, *Cardinia concinna*, *C. trapezium*, *Lima Hettangiensis*, *Plicatula Hettangiensis*, *Mytilus glaber*, *Littorina clathrata*, *Turritella nucleata*, *Hettangia Deshayesiana*, etc. On the other hand, the *Ammonites Bucklandi*-zone contains such characteristic Liassic species as the *Gryphæa incurva*, *Lima gigantea*, and *Hippopodium ponderosum*, and is further marked by the insetting of Belemnites.

According to M. Marcou the Lias of the Salinois Jura is divisible (in descending order) into,—

1. The Upper Lias, consisting of (1) supraliassic sandstone and oolitic iron-ore, with *Ammonites opalinus* and *A. bifrons*; (2) Marls and Shales (of Pinperdu), with *Trochus duplicatus* and *Ammonites radians*; and (3) bituminous schists (Schistes de Boll), with *Posidonomya Bronni* and numerous fishes.
2. The Middle Lias, consisting of (1) grey and sandy marls with *Plicatula spinosa* and *Ammonites spinatus*; (2) shales and marls with *Belemnites umbilicatus* and *Ammonites amaltheus* (*margaritatus*); (3) argillaceous limestones with *Belemnites acutus* and *Ammonites Davœi*; (4) marls and marlstones of Balingen with *Gryphæa cymbium* (*regularis*), *Ammonites raricostatus*, and *A. oxynotus*.
3. The Lower Lias, consisting of impure bluish limestone, with *Gryphæa arcuata*, *Cardinia concinna*, *Lima gigantea*, *Ammonites Bucklandi*, *A. angulatus*, etc.

The total thickness of all these beds does not there exceed 200 feet.

France and Belgium. Commencing near Mézières the Lias thence passes through a small section of South Belgium, traverses the Duchy of Luxembourg, and ranges through Lorraine and Burgundy to the Auxois. In the first of these districts it has been described by MM. Piette and Terquem[1], and in the latter by M. Collenot[2]. In the northern area the upper and middle divisions of the Lias are but slightly developed, the former being characterised by *Belemnites compressus* and *Ammonites communis*, and the latter by *Gryphæa cymbium*, and *Ammonites Davœi*, whereas the lower division of the Lias, characterised by the *Gryphæa arcuata* (*incurva*), *Am. complanatus*, and *A. angulatus*, together with the Hettangian series, are largely developed, especially in Luxembourg. The Hettangian and Lower Lias gradually become thinner as they range southward, while the upper divisions acquire greater importance, the Middle and Upper Lias attaining in Lorraine a thickness of about 600 feet, and the Hettangian being reduced to 10 or 12 feet. Throughout this district, and extending still further south, a valuable bed, 10 to 50 feet thick, of oolitic iron-ore, characterised by the presence of *Ammonites opalinus*, *Belemnites compressus*, *Gryphæa ferruginea*, *Trigonia navis*, etc., is worked near the top of the Upper Lias.

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[1] 'Le Lias Inférieur de l'est de la France comprenant la Meurthe, la Moselle, le Luxembourg, la Belgique, et la Meuse;' Mém. Soc. Géol. France, 2nde Sér., vol. viii.

[2] 'Description Géologique de l'Auxois,' p. 157.

The divisions of the Lias, with the order of the Ammonite-zones, in the Luxembourg and the Ardennes, are as under :—

Upper Lias = Toarcian	Zone of *Ammonites opalinus*, Pl. VII, fig. 2. „ *A. radians.* „ *A. serpentinus*, Pl. VI, fig. 8.
Middle Lias = Liassian	Zone of *Ammonites spinatus.* „ *A. capricornus*, Pl. VI, fig. 5. „ *A. planicostus.*
Lower Lias = Sinemurian.	Zone of *Ammonites bisulcatus.*
Infra-Lias = Hettangian . . .	Zone of *Ammonites angulatus*, Pl. VI, fig. 2. „ *A. planorbis*, Pl. VI, fig. 1.

M. Gosselet includes the Lower- and Infra-Lias in one division—the Sinemurian, which he divides into two subdivisions—the Upper Sinemurian and the Lower Sinemurian or Hettangian.

In the Auxois, the Lias attains a thickness of above 700 feet, and is rich in fossils, of which full lists will be found in M. Collenot's work before-named. The base of the Infra-Lias here consists of a fissile 'lumachelle' limestone, with *Ammonites planorbis*, *Ostrea irregularis*, and numerous other organic remains. This rock possesses some peculiar local mineral features, such as the great abundance here and there of siliceous matter, so that it often passes into a jasperoid rock, with the fossils silicified; while it is overlain by a fine-grained limonite, which forms a valuable iron-ore. To these succeed marlstones, and clays. Some bands in the Upper and Middle Lias make the fine hydraulic limes and cements of Vassy and Venarey.

The same divisions of the Lias, characterised by very much the same fossils, extend to the south of France. Another belt of Liassic strata ranges through Normandy, La Vendée, and Poitou. In these latter areas, the Lias, though thinner than in Dorsetshire, presents the same general features and fossils. At Caine and Curoy a clay at the base of the Upper Lias contains numerous calcareous nodules in which are found reptilian and fish remains—the latter often in an admirable state of preservation, and showing amongst the contents of the stomach remains of the Mollusca on which they fed.

Central Europe and Italy. The Lias extends through Suabia, the north-west of Germany, and Silesia; and is met with again in the Carpathians. The Jurassic series in Germany is divided into—

1. The White Jura, or Malm.
2. The Brown Jura, or Dogger.
3. The Black Jura, or Lias.

The Lias has not the thickness which it has in Western Europe, but the different zones are nevertheless well-marked. The following are Quenstedt's divisions and sub-divisions for Suabia; they are applicable generally to Germany:—

Upper Lias; 35 feet.	ζ. Light-grey Marls with *Ammonites Jurensis*, *A. radians*, *A. Aalensis*, *Belemnites acuarius*, *B. tricanaliculatus*, etc.
	ε. Shales with *Posidonomya Bronni*, *Ammonites communis*, *A. heterophyllus*, *A. bifrons*, *A. serpentinus*, *Belemnites acuarius*, *B. digitalis; Extracrinus Briareus; Lepidotus*, *Dapedius; Ichthyosaurus*, *Plesiosaurus*, *Teleosaurus*, etc.
Middle Lias; 90 feet.	δ. Pyritous clays with *Ammonites margaritatus* (*A. amaltheus*), *A. costatus*, *Belemnites paxillosus; Rhynchonella quinqueplicata; Pentacrinus basaltiformis*, etc.
	γ. Marls and Limestones with *Spirifera verrucosa*, *Ammonites Davœi*, *A. ibex*, *A. fimbriatus*, *Terebratula numismalis*, *Gryphæa cymbium*, etc.
Lower Lias; 120 feet.	β. Laminated Clays with *Ammonites oxynotus*, *A. Turneri*, *A. raricostatus*.
	α. *c*. Limestones and bituminous shales, with *Gryphæa arcuata* (*incurva*), *Ammonites Bucklandi*, *A. Conybeari*, *Lima gigantea*, *Spiriferina Walcotti*, *Pentamerus tuberculatus; Crustacea;* Fishes; Ichthyosaurians, etc.
	α. *b*. Soft Sandstones with *Ammonites angulatus*, *Cardinia concinna*, *Turritella nucleata*, etc.
	α. *a*. Marlstones, Clays, and bituminous Marlstones, with *Ammonites planorbis* (*A. psilonotus*, Quenst.), etc.

The two lower subdivisions α. *a* and α. *b* are the equivalents of the Infra-Lias and Hettangian of Western Europe.

Organic remains swarm in most places, to the extent often of rendering the shales and marlstones highly bituminous. Vegetable remains (Cycads and Conifers) are not common, except in the most eastern extension of the Lias in the Carpathians, where, in the Banat, the vegetable débris forms several beds of coal—some of them from two to three feet thick—of sufficient importance to be worked (at Fünfkirchen and Berszastzka). They seem to belong to the lower part of the Liassic series. Intercalated beds of oolitic iron-ore are not infrequent; and nodules of clay-ironstone are not uncommon in the shales, which also contains *Ammonites*, *Cardinia*, *Ceromya*, *Corbula*, etc.

The Lias is remarkable for the uniformity and persistence of its fossiliferous zones. This is forcibly shown in the valuable lists of organic remains in the Ammonite-zones of Britain and different parts of Europe, drawn up by the late Dr. Wright[1]. The distribution of the Ammonites is summed up in the following table:—

[1] Palæontographical Soc., vol. for 1878 and 1879. The reader should consult these monographs for the full information they give respecting both these and other fossils of Lias.

Table showing the extension through Europe of the Ammonite-Zones of the Lias (Wright, *Op. cit.*, pp. 65, 112, 164).

		British Islands.			Belgium.	France.						Switzerland.		Germany.		Austria.	Italy.
	Ammonite-Zones of the Lias.	England.	Ireland.	Scotland.	Luxembourg.	Normandy.	Côte-d'Or.	Yonne (Auxois).	Isère; Cher.	Rhone; Jura.	Aveyron.	Schaffhausen; Basel.	Aargau.	Hanover.	Würtemberg.	N.E. Alps.	Lombardy & Apennines, Tuscany.
Upper Lias.	opalinus	×	..	..	..	×	..	..	×	×	×	?	?	×	×	..	..
	jurensis	×	..	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	bifrons	×	..	×	×	×	×	×	×	×	×	×	×	×	×	×	×
	serpentinus ..	×	..	..	×	×	×	×	×	×	×	×	×	×	×	×	×
Middle Lias.	spinatus	×	..	×	..	×	×	..	×	×	×	..	..	×	×	..	×
	margaritatus ..	×															
	Henleyi	×	..	×	..	×	×	×	×	×	×	..	×	×	×	×	
	ibex	×	×	..	..	×	×	×	×	..	×	..	×	×	×	×	×
	Jamesoni	×	×	×	..	×	×	..	×	..	×	..	×	×	×	×	×
	armatus	×	×	×	..	..	×	..	×	..	..	..	..	×	×	..	..
Lower Lias.	raricostatus ..	×	×	..	..	..	×	×	..	×	..	×	..	×	×	×	×
	oxynotus	×	..	..	..	..	×	×	..	×	..	×	..	..	×	×	..
	obtusus	×	..	..	×	..	×	×	..	×	..	×	..	×	×	×	×
	Turneri	×	..	..	×	..	×	×	..	×	..	×	..	..	×	..	×
	Bucklandi ...	×	×	×	×	..	×	×	..	×	..	×	..	×	×	×	×
	angulatus	×	×	..	×	..	×	×	..	×	..	×	..	×	×	×	×
	planorbis	×	×	..	×	..	×	×	..	×	..	×	..	×	×	×	..

The Upper Jura or the Oolitic Series.

France. As with the Lias, the main divisions of the Oolitic series are alike in France and England; and a large number of the fossils are common to both countries, although distance and local peculiarities give rise to special distinctions and variations which often complicate questions of synchronism.

The Bas-Boulonnais is a district of peculiar interest, from the circumstance that it forms the eastern termination of the raised Wealden area of Kent and Sussex; but whereas in England the elevation has not brought to the surface any beds older than the Wealden, in France it has led to the exposure not only of the Palæozoic strata before described, but also of a nearly complete sequence of the Oolitic series[1]. At Hydrequent, near Marquise, unfossiliferous sands, representing possibly the Inferior Oolite, rest on inclined and denuded beds of Carboniferous Limestone. To these succeed marls with *Ostrea acuminata*, *Terebratula maxillata*, and *Rhynchonella concinna*, and a soft oolite—with *Clypeus Plottii* and *Holectypus depressus*,—the equivalent of the Fuller's-Earth and Great Oolite. Nearer Marquise is a compact oolite with *Rhynchonella elegantula*, *Terebratula digona*, *Pecten vagans*, *Avicula echinata*, *Anabacia complanata*, etc., referred to the Forest-Marble; and a marly oolite with *Terebratula lagenalis*, *T. obovata*, *Pholadomya lyrata*, etc., referred to the Cornbrash.

The surface of the Cornbrash (sometimes pierced by lithodomous perforations) is overlain by a ferruginous marl, with *Ammonites Calloviensis*, representing the Kelloway Rock, which passes upwards into dark clays with subordinate beds of compact limestone. These strata, worked near Houllefort, contain *Ostrea* (*Gryphæa*) *dilatata*, *Terebratula impressa*, *Rhodocrinus echinatus*, *Ammonites Lamberti*, *A. crenatus*, etc., and are the equivalents of the Oxford Clay.

The Coralline Oolite is well developed, attaining a thickness of 150 to 200 feet, near Houllefort and Hesdin-l'Abbé, and consists of grey marls with bands of rubbly oolite, containing *Cidaris florigemma*, *Hemicidaris intermedia*, *Pecten vimineus*, *Phasianella striata*, *Nerinæa Goodhallii*, *Rhynchonella inconstans*, *Isastræa explanata*, etc., but none of the ordinary Ammonites so common in England.

Of still greater importance is the Kimmeridge Clay, which here attains a thickness of about 360 feet, and exhibits a series of remarkably fine sections in the cliffs on either side of Boulogne. It consists of alternating beds of dark clays and thin argillaceous limestones, some of which make a good hydraulic cement. The lower beds contain *Ostrea deltoidea*, *Trigonia Bronni*, *Gervillia tetragona*, *Astarte Morini*, *Nerinæa Dewoidji*, *Ceromya excentrica*, and *Pygurus Jurensis*; while the upper beds are characterised by *Ammonites caletanus* (*longispinus*), *Gryphæa virgula* (very abundant), *Thracia depressa*, *Lingula ovalis*, etc. The upper division of the Kimmeridge Clay consists of a series of beds of sand, hard dark sandstones, and concretionary blocks, formerly referred to the Portland series, but now classed with the Kimmeridge, and for which the term 'Bolonian' has

[1] See E. Rigaux's 'Notice Stratigraphique du Bas-Boulonnais,' and Gosselet's 'Esquisse Géologique du Nord de la France.'

been proposed by Professor J. F. Blake. They are passage-beds containing both Kimmeridge and Portland fossils, amongst which are *Pteroceras oceani*, *Cyprina Brongniarti*, *Hemicidaris Purbeckensis*, *Trigonia Pellati*, *Ammonites gigas*, etc. To these succeed sands and calcareous sandstones with *Cardium dissimile*, *Perna Bouchardi*, *Ostrea expansa*, *Trigonia gibbosa*, *Ammonites giganteus*, etc., of Portland age; while a thin limestone overlying these, and containing *Astarte socialis* and *Cypridæ*, is referred to the Purbeck.

In the small anticlinal ridge of the 'Pays de Bray,' the Upper Kimmeridge and the Portland beds are again exposed, and are of interest from their containing, as they range southward, a conglomerate bed made up of old rocks, thus indicating the existence of an emerged Palæozoic land or island in that direction.

The Jurassic strata of Normandy[1] are noted for the frequent abundance and fine state of preservation of their fossils. The Inferior Oolite is represented in the neighbourhood of Bayeux by a ferruginous and very fossiliferous oolite with *Ammonites Murchisonæ*, *A. Sowerbyi*, *Lima heteromorpha*, *Astarte obliqua*, etc., succeeded by a fine white oolite with *Ammonites Parkinsoni*, *Terebratula Phillipsii*, and numerous *Spongidæ* and *Echinodermata*. The Great Oolite is represented by the celebrated '*Calcaire de Caen*' and the '*Calcaire de Ranville*.' In the freestones, organic remains are not numerous with the exception of *Belemnites Bessinus* and another species in the former, and of Polyzoa in the latter group of strata (whence its name of '*Calcaire à Bryozoaires*'). The Caen beds are, however, richer in reptilian and fish remains. It was there that the remains of the fine restored skeleton of *Teleosaurus Cadomensis*, figured at p. 207, was found.

Above these are thin beds of marl and limestone, abounding in Polyzoa, *Terebratula digona*, and other fossils—the equivalent of the Forest-marble. The Cornbrash has suffered denudation.

The Middle Oolites succeed unconformably, and are finely exhibited in the cliffs on the coast between Honfleur, Trouville, and Dives. The Oxford Clay is there about 300 feet thick, and characterised, as in England, by *Gryphæa dilatata*, *Ammonites Duncani*, *A. Lamberti*, *A. athletus*, *Terebratula impressa*, etc.

The Coral Rag of Trouville consists of rubbly oolites and grey marls, with *Cidaris florigemma*, *Echinobrissus scutatus*, *Opis Phillipsii*, *Chemnitzia Heddingtonensis*, *Trigonia Bronni*, *Ammonites Martelli*, etc.[2] The *Trigonia*

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[1] See E. Deslongchamps' 'Études sur les Terrains Jurassiques Inférieurs de la Normandie,' and 'Bull. Soc. Géol. de France,' 2nde Sér., vol. vi. p. 217.

[2] See M. Hébert's paper, 'Du Terrain Jurassique supérieur sur les Côtes de la Manche;' Bull. Soc. Géol. France, 2nde Sér., vol. xvii. p. 300; and M. Douvillé, *Ibid.* 3^me^ Sér., vol. ix. p. 441.

Bronni is very abundant in the Coral Rag of Normandy, and is said to occur at Weymouth and Osmington. It may be doubtful, however, whether this species is not merely a variety of *T. clavellata*, which has a very wide range both in England and on the Continent.

The Upper Oolites commence by the two lower subdivisions of the Kimmeridge, which are largely developed on the Continent and designated Sequanian and Pterocerian. They consist in Normandy of marls, siliceous limestones, and clays, together about 100 feet thick, with *Rhynchonella inconstans*, *Ostrea deltoidea*, *Astarte supracorallina*, *Ceromya excentrica*, *Pholadomya Protei*, *Pygurus Royeri*, *Pteroceras oceani*, *Pt. ponti*, etc.; and are succeeded by another division of the Kimmeridge Clay (the Virgulian), or the clays of Honfleur (where they are well exhibited), characterised by *Gryphæa virgula*, *Gervillia Kimmeridgensis*, *Ammonites longispinus*, *A. Lallieri*, etc.

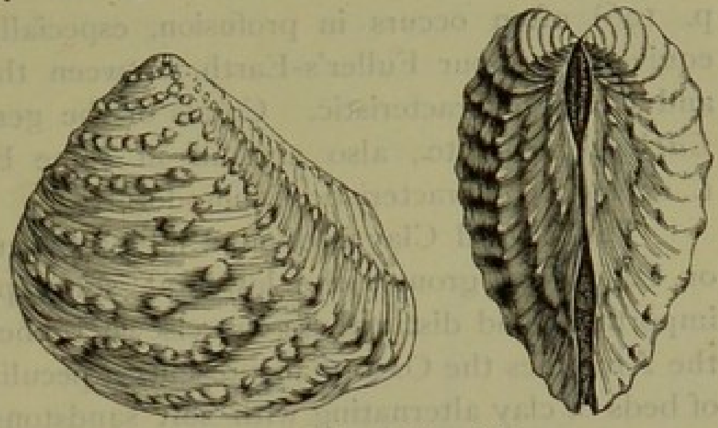

FIG. 127. *Trigonia Bronni*, Ag.

Oolitic strata again appear in the neighbourhood of Poitiers, skirting the central plateau of crystalline rocks, and ranging to La Rochelle, Angoulême, and nearly to Montauban. The Callovian is especially well developed, and is particularly rich in organic remains at Montreuil-Bellay. At La Rochelle a coralline bed (analogous to the Coral Rag) occurs in the middle of the Kimmeridge; while in the Lower Oolite of Niort there is a sponge-bed similar to the curious sponge-beds of the Jura, of which we shall speak presently. For information on the geology of these districts, I would refer the reader to the works of M. de Longuemar, M. Coquand, and others.

For the large and important zone of Oolitic strata of the north-east of France, ranging from Mezières to Metz, Passy, Dijon, Auxerre, and Nevers, works of MM. Sauvage and Buvignier[1], Gosselet[2], Tornbeck, Roger and de Loriol[3], Jules Martin[4], Collenot[5], Dr. Wright[6], and others should be consulted.

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[1] 'Statistique Minéralogique et Géologique du Département des Ardennes.'

[2] 'Esquisse Géologique du Nord de la France.'

[3] 'Description des Étages Jurassiques Supérieurs de la Haute-Marne.'

[4] 'Mém. de l'Acad. de Dijon,' vol. v.

[5] 'Description Géologique de l'Auxois.'

[6] 'On the Correlation of the Jurassic Rocks in the Department of the Côte-d'Or with the Oolitic Formations of Gloucester and Wilts,' Gloucester, 1872. This exhaustive paper treats of other parts of France besides the Côte-d'Or.

Throughout this district the Lower Oolite maintains its general calcareous and oolitic structure, more or less marly in places, with a thickness of from 200 to 300 feet; and, although new species of fossils appear, certain forms, such as *Ammonites Murchisonæ*, *A. Parkinsoni*, *A. Humphriesianus*, *Anabacia orbulites*, *Terebratula digona*, *T. Phillipsii*, and *Rhynchonella elegantula*, are persistent; while the small *Ostrea acuminata* (Fig. 96*, p. 196) often occurs in profusion, especially in a particular zone, the equivalent of our Fuller's-Earth, between the Inferior and Great Oolite, and is very characteristic. Corals of the genera *Isastræa*, *Thammastræa*, *Latimæandra*, etc., also abound in some beds. *Collyrites ringens* and *C. ovalis* are characteristic Echinoderms.

The Oxford Clay is divided into a lower, or Callovian, and an upper, or Oxfordian, group; the lower at some places acquiring considerable importance and distinctness, but elsewhere they are difficult to separate. In the Ardennes the Oxfordian presents a peculiar feature. It there consists of beds of clay alternating with soft sandstones, much resembling some of the upper greensands and firestones of Surrey, and containing as much as 56 per cent. of *soluble silica*: the whole forms a mass about 300 feet thick. Further south it becomes more calcareous and ferruginous; the iron oxide sometimes forming bands of oolitic iron-ore. These beds are commonly characterised by *Ammonites cordatus*, *A. macrocephalus*, *A. Bakeriæ*, *A. biplex* (?), *Gryphæa dilatata*, *Plicatula tubifera*, *Trigonia clavellata*, etc.

A character important to notice is that in the Côte-d'Or, a marl characterised by sponges, sets in on the top of the Oxfordian, forming a passage-bed between it and the Corallian. These 'Marnes à spongiaires' contain *Ammonites canaliculatus*, *A. eucharis*, *Terebratula bucculenta*, *T. tetragona*, *Trigonia clavellata*, *Cidaris coronata*, etc. Above these there is, at places, a series of thin-bedded compact limestones (calcaires pseudo-lithographiques) with *Ammonites plicatilis*, *Pholadomya parcicosta*, *Melania striata*, etc. These strata form M. Marcou's 'Argovian,' a subdivision largely developed in Switzerland.]

The Coralline Oolite attains in the Ardennes a thickness of about 400 feet, diminishing as it ranges southward in the Meuse and Haute-Marne, and containing *Cidaris florigemma*, *Echinus perlatus*, *Glypticus hieroglyphicus*, *Thecosmilia annularis*, *Isastræa explanata*, etc. There is here also an upper zone, characterised by a profusion of *Diceras arietinum* and *Nerinæa Defrancii*, which is wanting in England. These two zones, characterised respectively by *Glypticus hieroglyphicus* (Pl. VIII, fig. 11) and *Diceras arietinum*, belong to the reef-beds of the Coralline Oolite, but in the deeper waters between these reefs marls were synchronously deposited with a more pelagic fauna, of which the characteristic species are *Ammonites bimammatus* and *A. Marantianus*.

The Kimmeridge formation is divided (in descending order) into the Bolonian, Virgulian, Pterocerian, and Sequanian groups. The Sequanian presents in the east of France a prevailing oolitic structure, passing in Burgundy into a chalky limestone with bands of flint. Amongst the more common fossils are *Astarte minima*, *Diceras arietinum*, *Rhynchonella corallina*, and *Trichnites Saussurei*, while in places there are coral-banks with 'Corallian' species of Echinoderms, such as *Cidaris florigemma*, etc.

The *Diceras arietinum* from its great abundance gives its name '*Dicératien*' to a zone of the Kimmeridgian; for the same reason a zone or subdivision of the Coral Rag is termed '*Ptérocérien*' from the *Pteroceras oceani*.

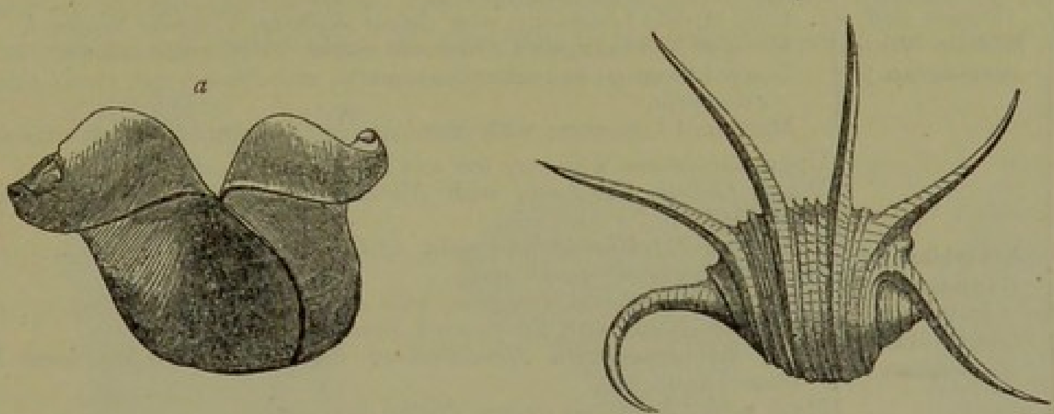

FIG. 128. *a. Diceras arietinum*, Lam. *b. Pteroceras oceani*, Brong.

The Pterocerian strata pass as they range south into compact (lithographic?) limestones, with *Terebratula* (*Waldheimia*) *humeralis*, *Goniolina geometrica*, *Pteroceras ponti*, etc. The Virgulian, with *Gryphæa virgula*, *Pholadomya multicostata*, and *Thracia depressa*, retains a prevailing argillaceous structure. The Bolonian is characterised by *Ammonites gigas*, *A. suprajurensis*, *Cyprina Brongniarti*, etc.

The Portlandian series consists sometimes of calcareous sandstones, and at other times of oolitic beds, with *Trigonia gibbosa*, *Ammonites giganteus*, *Cyrena rugosa*, etc.

In approaching the Department and mountains of the Jura the Oolitic series becomes further developed, and loses much of the characters which it possesses further to the west; and fresh-water beds of Purbeck age, with *Corbula Forbesi*, *Planorbis Loryi*, *Physa Waldiana*, *Chara*, *Emys*, etc., re-appear.

In this area, as before mentioned, all the Jurassic strata are largely developed and their subdivisions well marked. In the Swiss Jura, on the contrary, the Liassic strata are not so well exhibited; while the Oolitic and Cretaceous strata are, on the other hand, largely developed[1].

[1] See both the works of M. J. Marcou and M. A. Jacquard before quoted.

Divisions of the Upper Jura of Switzerland.

Upper Jurassic Series. (Upper Oolites.)	**Purbeckian**; 20 *mètres.*	Oolites, with brackish-water fossils—*Corbula Forbesiana, Cerithium Villeneuve.*
		Fresh-water Marls, with *Planorbis Loryi, Valvata helicoides.*
		Gypseous marls and dolomitic breccia (*Cargneule*).
		Cellular dolomites and Limestone, with *Corbula inflexa, Cardium Purbeckense.*
	Portlandian or Nerinæan; 50 *mètres.*	Marls and dolomitic limestone, with *Pinna suprajurensis, Nerinæa trinodosa, Pteroceras oceani*, etc.
		Magnesian Marls, with *Trigonia gibbosa.*
		a. Compact white Limestone, with *Natica Marcousana, Ammonites gigas, Gryphæa virgula*, var., *Pycnodon gigas, Strophodus subreticulatus.*
	Pterocerian; 150 *mètres.* (**Upper and Middle Kimmeridgian.**)	*b.* Magnesian Marls, with *Gryphæa virgula, Nerinæa depressa.*
		Upper Polyzoan Limestone, with *Diceras suprajurense, Pygurus Jurensis, Nerinæa Bruntutana.*
		Marl, with *Ostrea Bruntutana.*
		c. Grey Middle Limestone, with *Ostrea solitaria, Trichites Saussuri.*
		Marls of Noirvaux, with *Pteroceras oceani, Terebratula subsella.*
		Lower Limestone and subordinate marls, with *Pholadomya Protei, Ceromya excentrica.*
		Marls and Limestone, with *Hemicidaris Thurmanni, Ostrea solitaria.*
	Astartian or Sequanian; 140 *mètres.* (**Lower Kimmeridgian.**)	Upper Limestone, with very few and little known fossils.
		White Oolitic limestone, with *Nerinæa Mandelslohi* and a species of *Trochus.*
		Marl, with *Terebratula humeralis, Apiocrinus Meriani.*
		Middle Limestone—fossils rare.
		Marls and lumachelle, limestone, with *Astarte gregaria.*
		Oolitic limestone, with *Terebratula humeralis.*
		Marly limestone, with *Hemidiadema Gagnebini, Pseudodiadema hemisphæricum.*
		Marl, with *Chemnitzia striata, Natica helvetica.*
		Lower marly Limestone, with *Acrocidaris nobilis, Cidaris Blumenbachii, C. florigemma.*

a. is probably the Bolonian, *b.* the Virgulian, and *c.* the Pterocerian of some writers.

Middle Jurassic Series. (*Oxfordian, or Middle Oolites.*)	**Corallian**; 20 *mètres.*	Marls and siliceous Limestone, with *Pholadomya acuticostata, Cidaris florigemma, Hemicidaris crenularis, Lima rigida*, etc.
		Marl, with *Glypticus hieroglyphicus, Stomechinus perlatus, Stylina, Montlivaltia, Thamnastræa*, etc.
	Pholadomyan (Argovian); 100 *mètres.*	Limestone, with *Pholadomya hortulana.*
		Upper hydraulic Limestones, with few fossils.
		Lower hydraulic Limestones and Marls, with *Hemithyris spinosa, Ammonites biplex, Belemnites hastatus, Gryphæa dilatata, Arca concinna*, etc.
	Spongitian; 12 *mètres.*	Sponge Limestone (*Calcaire à scyphies*), with *Pentacrinus subteres, Terebratula bisuffarcinata, Cidaris coronata, Ammonites transversarius, A. plicatilis, Pholadomya acuminata*, etc.
	Callovian; 3 *mètres.*	Marls, with *Ammonites anceps, A. Lamberti, Belemnites hastatus, Terebratula digona, Rhynchonella triplicosa.*
Lower Jurassic Series. (*Lower Oolites.*)	**Bathonian**; 50 *mètres.*	Fossiliferous fissile Limestones (*Dalles nacrées*), with *Ostrea acuminata, Pentacrinus Nicoleti, Pecten lens, Terebratula coarctata*, etc.
		Marls and Hydraulic Limestones of Noiraigne (*Marnes à discoïdes*), with *Terebratula perovalis, Pholadomya bucardium, Dysaster* (*Collyrites*) *ringens, Clypeus Osterwaldi, Gervillia acuta, Pecten vagans*, etc.
	Ledonian; 40 *mètres.* (**Bajocien.**)	Oolitic Limestone (*Grande Oolite*), with *Pecten.*
		Marly Limestone (*Calcaire à polypiers*), with *Cidaris Courtandina, Rhynchonella concinna, Ostrea Marshii, Isastræa tenuistriata, Thecosmilia gregaria*, etc.
		Rubbly limestone, with *Pentacrinus* and fossils in fragments.

Although more largely developed, the Oolitic series are less fossiliferous in the Swiss than in the French Jura. A change takes place also in the petrological character of the rocks, which are more massive, and their different zones present less distinctive characters. Consequently the facies of the rocks varies considerably in the different regions of the Jura, and the section above given only stands for one part[1].

There are two points of particular interest to be noted—one is the importance and number, in some of the strata, of siliceous sponges belonging to the *Hexactinellidæ* and *Lithistidæ*, indicating therefore sedimentation in waters of considerable depth; and the other is the multiplication of beds representing old coral-reefs, and indicative of shallow water and littoral conditions. The sponge-beds set in at the top of the Callovian are repeated in the Argovian, and again in the lower part of the Astartian. While these are thus frequent in the Oxfordian period, coral-reefs are repeated at two horizons of the Kimmeridgian period—one being in the Pteroccrian and the other in the Virgulian subdivision. In these reefs

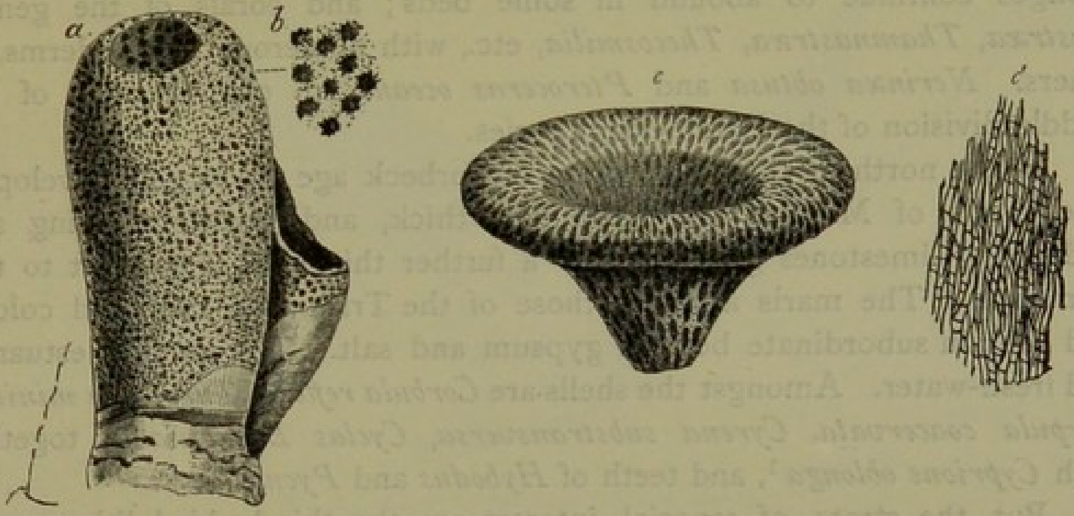

FIG. 129. *a* and *b*. *Scyphia milleporata*. *c*. *Ventriculites* (*Cribrospongia*) *reticulata*; *c'*. *Surface enlarged.*

not only is there a recurrence of the same genera, but often of the same species,—species supposed to be characteristic of the Coralline-Oolite period; this has not unfrequently led to mistakes respecting the true position of these several zones.

The profusion of Sponges, chiefly species of *Scyphia*, is such that for certain zones of the Middle and Upper Oolites it has obtained for them the names of '*Marnes à Spongiaires*,' and '*Scyphien-Kalk*.'

Germany. The Upper Jurassic series ranges through Würtemberg and Bavaria, and thence in one direction northward to Hanover and Westphalia, and in the other to Silesia and Poland. The lower division of the Brown Jura (or the Dogger) is the equivalent of our Lower Oolites; and the upper, of the Middle Oolites or Oxford series; while the White Jura

[1] The reader should consult the Report of the meeting of the Geological Society of France in the Jura in August, 1885, when many important questions connected with the structure and palæontology of the Jura were discussed. A list of the publications relating to the Geology of the Jura is given with the Report in the 'Bull. Soc. Géol. de France,' 3me Sér., vol. xiii. pp. 650–894.

is the equivalent of our Upper Oolites. The lower beds of the Brown Jura are generally argillaceous and ferruginous, with *Ammonites opalinus*, *A. Murchisonæ*, *Pecten pumilus*, *Nucula Hammeri*, *Trigonia navis*, etc. In Würtemberg it contains several beds of oolitic iron-ore. To this succeed light-coloured oolites with *Ammonites Humphriesianus*, *Ostrea Marshii*, *Gresslya abducta*, *Belemnites giganteus*, etc. Argillaceous beds with oolitic iron-ore again prevail in the upper division, which is characterised by *Ammonites Parkinsoni*, *A. macrocephalus*, *Belemnites canaliculatus*, *Trigonia costata*, *Avicula echinata*, and *Terebratula digona*. The upper subdivision consists of clays, with *Ammonites Lamberti*, *A. Jason*, *A. ornatus*, etc.

The White Jura (or Malm) attains great importance in Germany, and consists of massive and fissile white limestones, in some places compact, and in others oolitic, and often very fossiliferous. In Würtemberg siliceous sponges continue to abound in some beds; and corals of the genera *Isastræa*, *Thamnastræa*, *Thecosmilia*, etc., with numerous Echinoderms, in others. *Nerinæa obtusa* and *Pteroceras oceani* are characteristic of the middle division of the Kimmeridge series.

In the north of Germany, strata of Purbeck age are largely developed. The marls of Münder are 1,000 feet thick, and some overlying and underlying limestones give together a further thickness of 500 feet to this formation. The marls are, like those of the Trias, of a deep red colour, and contain subordinate beds of gypsum and salt. The fauna is estuarine and fresh-water. Amongst the shells are *Corbula reflexa*, *Turritella minima*, *Serpula coacervata*, *Cyrena substransversa*, *Cyclas Brongniarti*, together with *Cyprione oblonga*[1], and teeth of *Hybodus* and *Pycnodus*.

But the strata of especial interest are the thin-bedded lithographic limestones of Kimmeridgian age (Upper Pterocerian) of Solenhofen in Bavaria. They form a mass about 80 feet thick, and owing to the fine impalpable nature of the original silt, the fossils are in a wonderful state of preservation: Annelids entire; Insects with the most delicate nervation of their wings; Crustaceans with their antennæ; Cuttle-fishes with their tentacles and ink-bags; and Fishes with every scale in place. There are also skeletons of *Pterodactylus* and *Rhamphorhynchus* with all the limbs, and in some instances with the impress of their leathery wings left on the stone. Such is the case with the remarkable specimen in the possession of Professor Marsh, of which a figure, reduced from his large plate, is annexed.

These beds have also furnished the only two known specimens of

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1 It has been stated that 'Cypris' occurs in the North-German (Hanoverian) Purbeck; but Prof. Rupert Jones informs me that this statement is erroneous. There is no 'Cypris' at all, though species of Cypridea, such as *C. punctata*, Forbes; *C. Dunkeri*, Jones; *C. tuberculata*, Sby.; *C. granulosa*, Sby.; *Cyprione Bristovii*, Jones; *C. oblonga*, Römer; and *Darwinula leguminella*, Forbes, are abundant; 'Quart. Journ. Geol. Soc.' vol. xli. p. 319 &c.

Archæopteryx—the earliest of known birds—with their bones and feathers. These birds, which were about the size of a rook, differ from all others

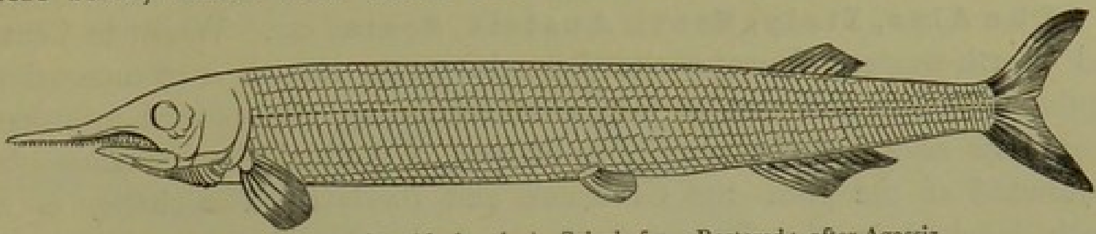

FIG. 130. *Lepidosteus* (*Aspidorhynchus*); Solenhofen. Restored: after Agassiz.

in having two free claws belonging to the wing, and a long lizard-like tail composed of twenty-one to twenty-three separate vertebræ,—each

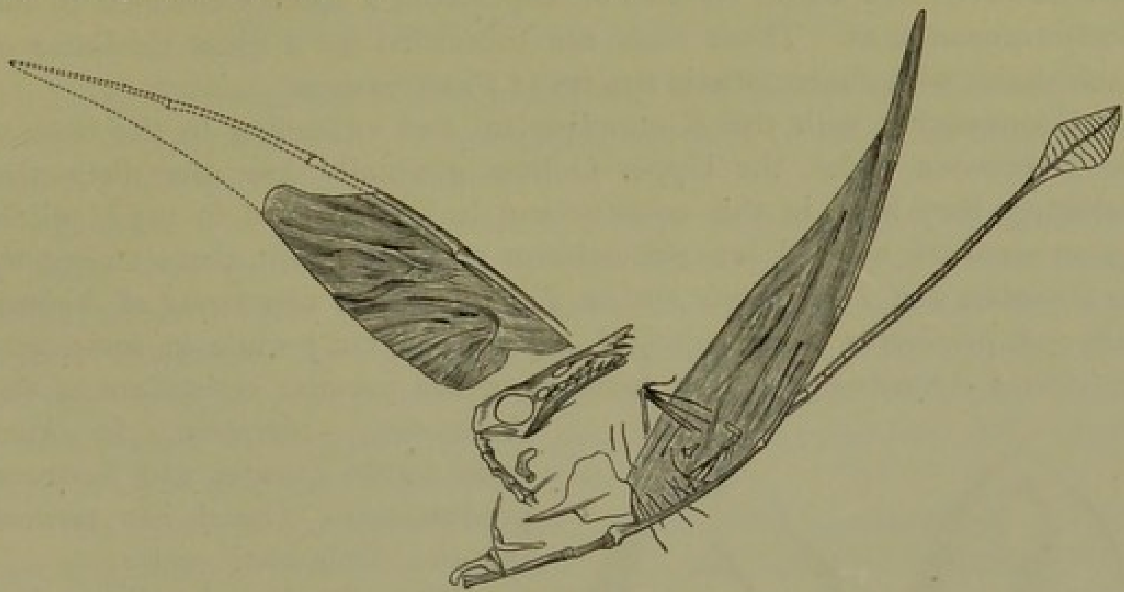

FIG. 131. *Rhamphorhynchus phyllurus*, Marsh, ½.
A unique specimen showing the impressions of the wings from the lithographic stone of Eichstadt, Bavaria, in the possession of Professor Marsh. 'Amer. Journ. Science,' April, 1882.

vertebra carrying a pair of quills. The jaws also were furnished with

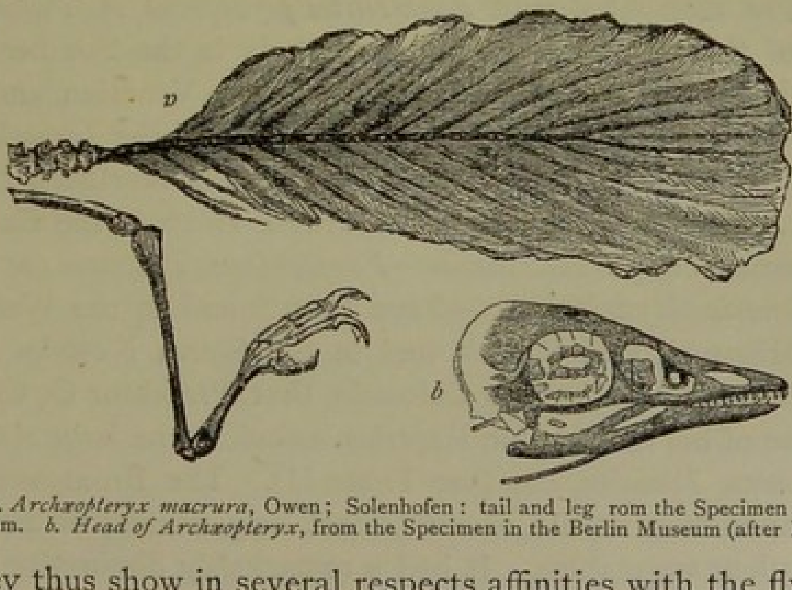

FIG. 132. *a. Archæopteryx macrura*, Owen; Solenhofen: tail and leg rom the Specimen in the British Museum. *b. Head of Archæopteryx*, from the Specimen in the Berlin Museum (after Dames).

teeth. They thus show in several respects affinities with the flying reptiles.

Russia. The Oolitic series is largely developed in the district around

Moscow, but with marked differences from the Western types. Still there are found such fossils as *Ammonites catenulatus*, *A. Jason*, etc.

The Alps, Italy, South Austria, Spain, etc. Whilst in Central and North-western Europe the Jurassic series retains a comparatively similar structure and similar fossils, all indicating the general prevalence of shallow seas and the proximity of land, a marked change takes place southward of the Jura, the Cevennes, and Bavaria. The change is not much marked in the Lower Oolites, which, though they thicken out greatly (to the extent of 1,500 feet or more), still retain their distinctive zones of *Ammonites Murchisonæ*, *A. Humphriesianus*, and *A. Parkinsoni*, with, however, new forms such as *A. tripartitus*, a species confined to the Mediterranean area. These beds are succeeded by a great thickness of black shales with characteristic species of *Posidonomya*.

Commencing with the Kimmeridgian, and extending to the base of the Cretaceous series, the Upper Oolites gradually lose the distinctive characters they have in this country and in France: and, in the Mediterranean area, are merged into one uniform pelagic deposit, characterised by the abundance of *Terebratula diphya*, *T. janitor*, and new forms of Ammonites—*A. ptychoicus*, *A. Staszyci*, *A. transitorius*, etc.; while in some beds (*Schistes à Aptychus*) are vast numbers of the peculiar operculum of the Ammonite — *Aptychus*. In other beds, corals, sponges, and Nerinææ predominate. Oppel has termed this the 'Tithonian' series.

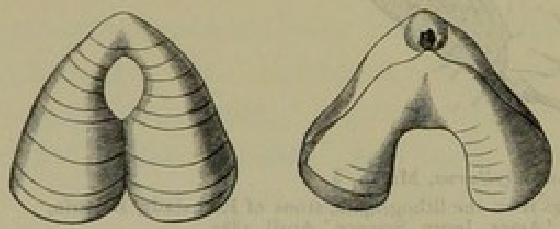

FIG. 133. *Terebratula diphya*, Col.

The *Terebratula diphya* has an extraordinary development in Southern Europe, and gives its name to the *Diphya-Kalk* and *Calcaires à Diphya*, associated with *Ammonites ptychoicus*, *A. Valonensis*, etc.

Strata of this character are present largely in the Southern Alps, the Apennines, the mountains of Southern Tyrol, the Venetian and Dalmatian Alps, and the Carpathians. The Tithonian type of the Jurassic series extends also across the Mediterranean to the strata of Northern Africa.

North America. There are no Jurassic strata in the Eastern States of North America, but Jurassic fossils—*Pentacrinus*, *Trigonia* (or *Myophoria*), *Gryphæa*, *Monotis*, *Myacites*, etc.—have been found in the Western States of Dakota, Missouri, and Uintah, and in the Sierra Nevada. It is from fresh-water beds of this age in Colorado that Professor O. C. Marsh has obtained some of his remarkable Reptiles, including the huge *Atlantosaurus*, the *Brontosaurus*, *Tinodon*, etc. (see Table II). The Brontosaurus was an enormous amphibious reptile, about 50 feet long, feeding on aquatic plants or other succulent vegetables. It had a remarkably diminutive head, while each footprint must have been about a square yard in extent.

In **South America** Jurassic rocks have been recognised by Pissis and David Forbes in the Andes of Chili and Peru.

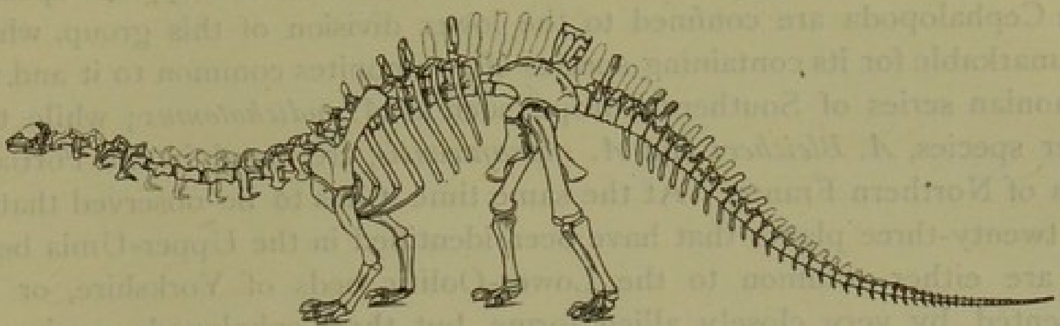

FIG. 134. *Restoration of Brontosaurus excelsus.* (After Marsh.)

Some European forms of Cephalopods, such as *Ammonites Humphriesianus*, *A. macrocephalus*, *A. biplex*, etc., are said to occur in these rocks both in South and North America.

India. The intimate relation of a large portion of the Jurassic series of India with those of Europe is very remarkable. The whole of the Oolitic series is there represented; but it is doubtful whether the Lias exists. The Upper Tagling Shales, formerly considered to be of the Liassic, are now thought to be Upper Jurassic. In Cutch there are strata of the Lower, Middle, and Upper Oolitic stages, well characterised by their fossils. They are also met with in the Madras Presidency.

The Pachham sandstones, shales, and limestones, containing *Corbula pectinata*, *Astarte compressa*, *Cucullæa virgata*, *Rhynchonella* (near *R. concinna*), an Ammonite—a variety of *A. macrocephalus*—and other fossils, are supposed to be on the horizon of the Bath Oolite. The Chári group of shales, with subordinate oolitic and other limestones and sandstones, of Northern Cutch, contain a rich fauna of 112 species, of which, according to Dr. Waagen, thirty-seven are European; amongst these are *Ammonites macrocephalus*, *A. athleta*, *A. perarmatus*, *A. Lamberti*, *A. cordatus*, with *Terebratula sella*, var. *T. biplicata*, etc. These strata are homotaxial with the Callovian and Oxfordian of Europe.

To these succeed the white, brown, and grey sandstones, and grey and reddish shales of the Katrol group of Cutch. The Kantkot sandstone seems to form passage-beds, several Ammonites being common to the Chári group, while the Belemnites are those of the Katrol proper. The latter has yielded twenty-two species of Ammonites, of which four species are found in the Kimmeridge beds of Europe. Amongst the plants there are also some European species, such as *Alethopteris Whitbiensis*, *Sphenopteris arguta*, *Otozamites contiguus*. This group is therefore considered to represent the Upper-Oxford and the Kimmeridge series.

The Umia group consists of sandstones of various sorts, upwards of 3,000 feet thick, or equal to all the other Jurassic beds together. In some places carbonaceous shales occur, with a seam of bright coal. Towards the base of the group there is a thick band of calcareous conglomerate. Marine fossils are rare,—*Trigonia Smeei* and *T. ventricosa* are typical species. The Cephalopoda are confined to the lower division of this group, which is remarkable for its containing species of Ammonites common to it and the Tithonian series of Southern Europe, such as *A. endichotomus*; while two other species, *A. Bleicheri* and *A. suprajurensis*, are found in the Portland beds of Northern France. At the same time it has to be observed that of the twenty-three plants that have been identified in the Upper-Umia beds, ten are either common to the Lower-Oolitic beds of Yorkshire, or represented by very closely allied forms, but the Cephalopoda again are distinctly Upper Jurassic.

Amongst other fossils occurring in the lower groups of the Cutch Jurassics are species of *Pleurotomaria*, *Pholadomya* (*P. graduosa*), *Corbula* (*C. lyrata*), *Cucullæa* (*C. virgata*), *Trigonia* (*T. costata*), and *Ostrea* (*O. Marshii*).

Upper-Jurassic strata are also represented in the Punjab and the Himalayas. The Jurassic series of India presents many points of analogy with some of the groups of Australia and South Africa[1].

Australia. Strata of Jurassic age exist in New South Wales and in Victoria. In the former they consist of argillaceous shales and thick sandstones, termed the 'Wianamatta series,' with a very limited fresh-water fauna (*Unio* and *Palæoniscus*), and plants of the genera *Thinnfeldia* (*Pecopteris*) and *Tæniopteris* (*T. Daintriei*). In Victoria, beds of this age constitute the important 'Carbonaceous Formation,' which is 5,000 feet thick, and contains the same fossils as the above, together with species of *Sphenopteris*, *Zamites*, and *Phyllotheca*[2]. Jurassic strata have also been met with in Queensland.

New Zealand. The Catlin river and Bastion series, containing species of *Ammonites*, *Clavigera*, and *Athyris* (!), are considered to be of Liassic age; while the Mataura and Putataka series are supposed to be of Upper Jurassic age. The former has an abundant flora of *Cycadites*, *Camptopteris*, *Tæniopteris*, *Alethopteris*, etc., and the latter has a marine fauna with *Terebratula*, *Rhynchonella*, *Epithyris*, *Spirifera* (*S. rostrata*), etc.

South Africa. The Uitenhage Formation, which consists of saliferous strata, sandstones, limestones, shales, and conglomerates, represents the whole of the Jurassic series. The upper division contains Ammonites, Belemnites,

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[1] For full details of these Indian Formations, Medlicott and Blanford's 'Manual of the Geology of India,' pp. xxxvii, xlviii, 256, 635, should be consulted.

[2] The range in time of the Cycadeæ is much greater in the Eastern than in the Western hemisphere.

PLATE VI.

MESOZOIC CEPHALOPODA.

Jurassic Ammonites.

Lower Lias.

1. Ammonites (*Ægoceras*) angulatus, *Schloth.*
2. Ammonites (*Ægoceras*) planorbis, *Sby.*
3. Ammonites (*Amaltheus*) oxynotus, *Quenst.*
4. Ammonites (*Arietites*) raricostatus, *Zeit.*

Middle Lias.

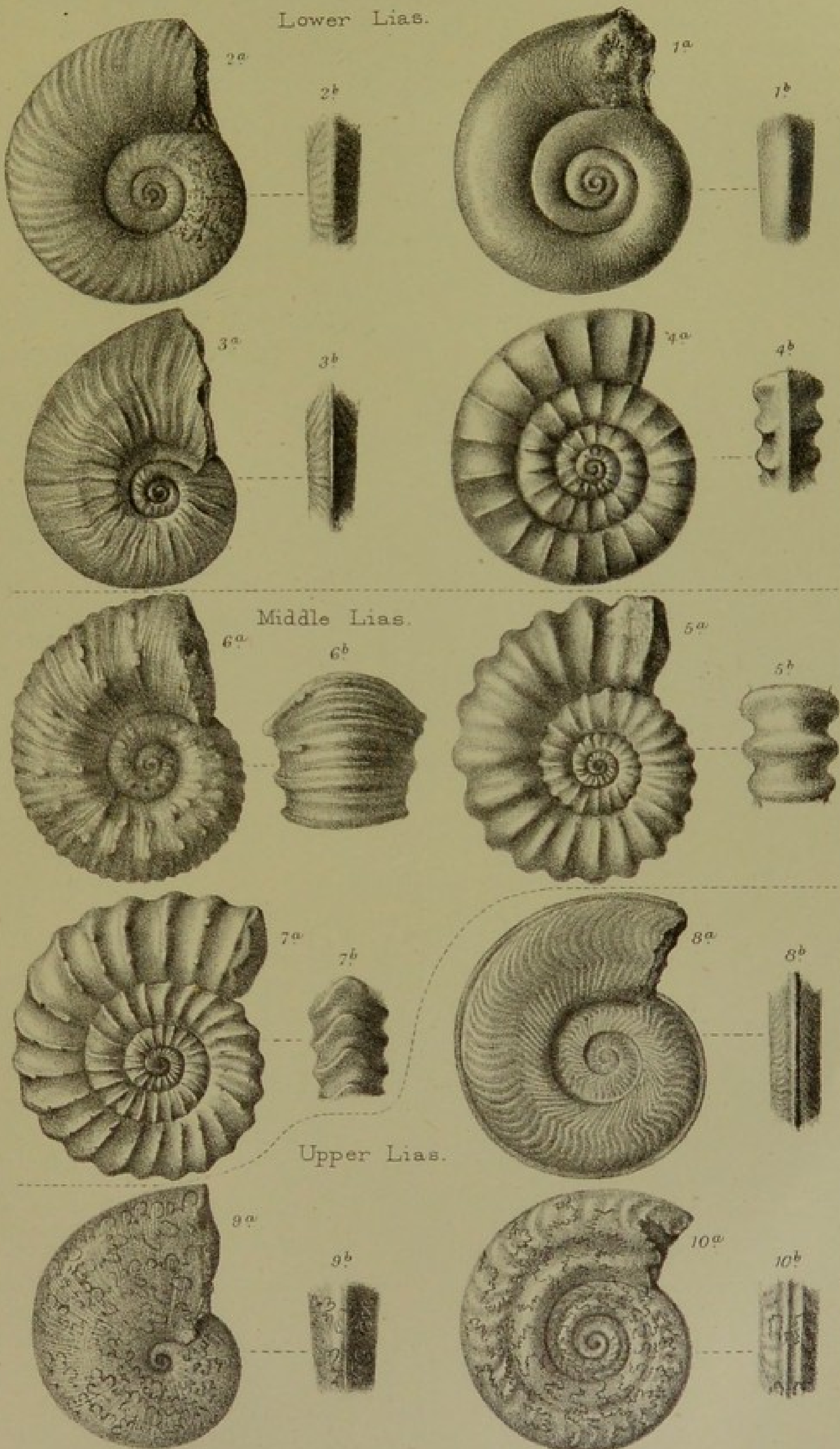
5. Ammonites (*Ægoceras*) Henleyi, *Sby.*
6. Ammonites (*Ægoceras*) capricornus, *Schloth.*
7. Ammonites (*Ægoceras*) brevispina, *Sby.*

Upper Lias.

8. Ammonites (*Harpoceras*) serpentinus, *Rein.*
9. Ammonites (*Phylloceras*) heterophyllus, *Sby.*
10. Ammonites (*Harpoceras*) bifrons, *Brug.*

Plate VI.

MESOZOIC CEPHALOPODA:—JURASSIC AMMONITES.



G. M. Woodward del. et lith.

Prestwich's Geology, II. — Clarendon Press.

PLATE VII.

MESOZOIC CEPHALOPODA.

JURASSIC AMMONITES.

Lower Oolites.

1. Ammonites (*Harpoceras*) Murchisonæ, *Sby.*
2. Ammonites (*Harpoceras*) opalinus, *Rein.*
3. Ammonites (*Stephanoceras*) Humphriesianus, *Sby.*
4. Ammonites (*Stephanoceras*) Braikenridgii, *Sby.*
5. Ammonites (*Cosmoceras*) Parkinsoni, *Sby.*

Middle Oolites.

6. Ammonites (*Stephanoceras*) Herveyi, *Sby.*
7. Ammonites (*Amaltheus*) Waterhousii, *Lyc. and Morr.*
8. Ammonites (*Cosmoceras*) Jason, *Sby.*
9. Ammonites (*Aspidoceras*) perarmatus, *Sby.*

Upper Oolites.

10. Ammonites (*Perisphinctes*) biplex, *Sby.*

Plate VII.

MESOZOIC CEPHALOPODA:—JURASSIC AMMONITES.

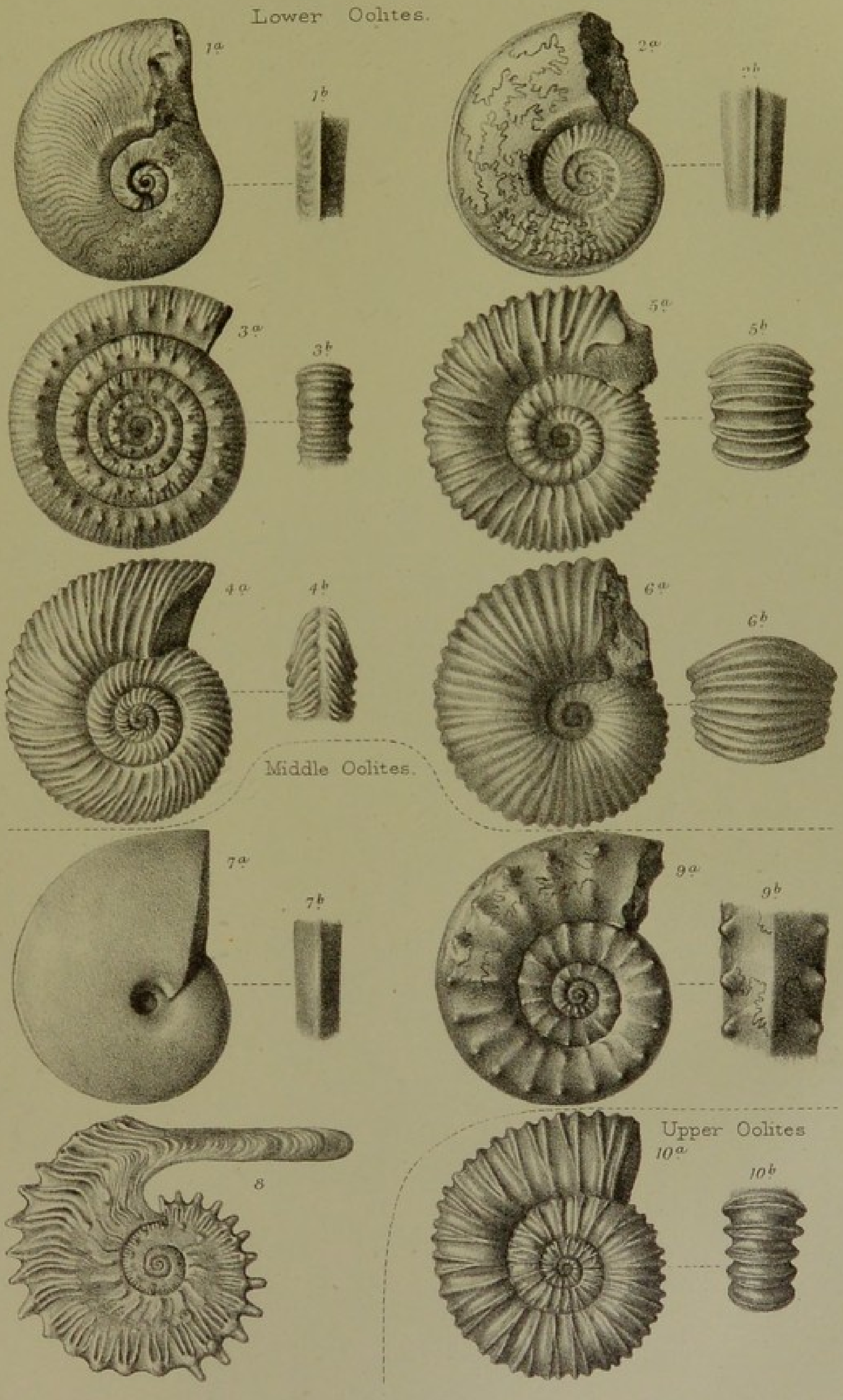


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PLATE VIII.

MESOZOIC ECHINODERMATA.

Jurassic.

Lias.

1.	Hemipedina Etheridgii, *Wright.* ...	*Lower Lias.*

Lower Oolites.

2.	Echinobrissus clunicularis, *Llhwyd.* ...	*Inferior Oolite to Cornbrash.*
3.	Holectypus depressus, *Leske.*	,, ,,
4.	Hyboclypus gibberulus, *Agass.*	*Inferior Oolite.*
5.	Acrosalenia spinosa, *Agass.*	*Inferior Oolite to Cornbrash.*
6.	Clypeus Plottii, *Klein.*	,, ,,
7.	Polycyphus Deslongchampsii, *Wright* ...	*Inferior Oolite.*
8.	Collyrites ringens, *Agass.*	*Inferior Oolite to Cornbrash.*

Middle Oolites.

9.	Pygaster umbrella, *Agass.*	*Coralline Oolite.*
10.	Hemicidaris intermedia, *Hem.*	,,
11.	Glypticus hieroglyphicus, *Goldf.* ...	,,
12.	Stomechinus gyratus, *Agass.*	,,
13.	Pygurus Blumenbachii, *Koch. and Dunk.*	,,
14.	Pseudodiadema mamillanum, *Roem.* ...	,,
15.	Cidaris florigemma, *Phil.*	,,

Plate VIII.

MESOZOIC ECHINODERMATA,—JURASSIC.

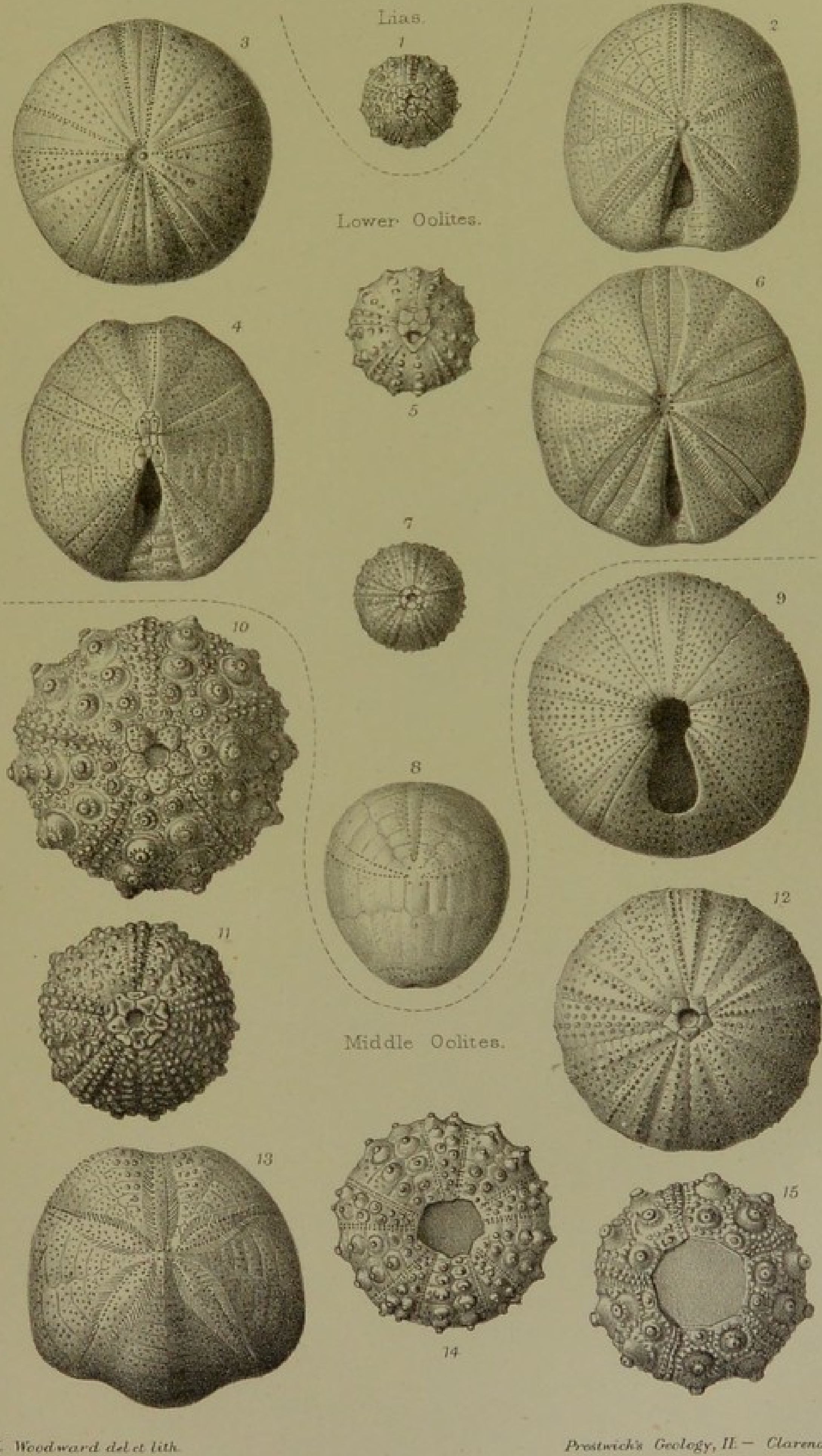

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PLATE IX.

MESOZOIC MOLLUSCA.

JURASSIC.

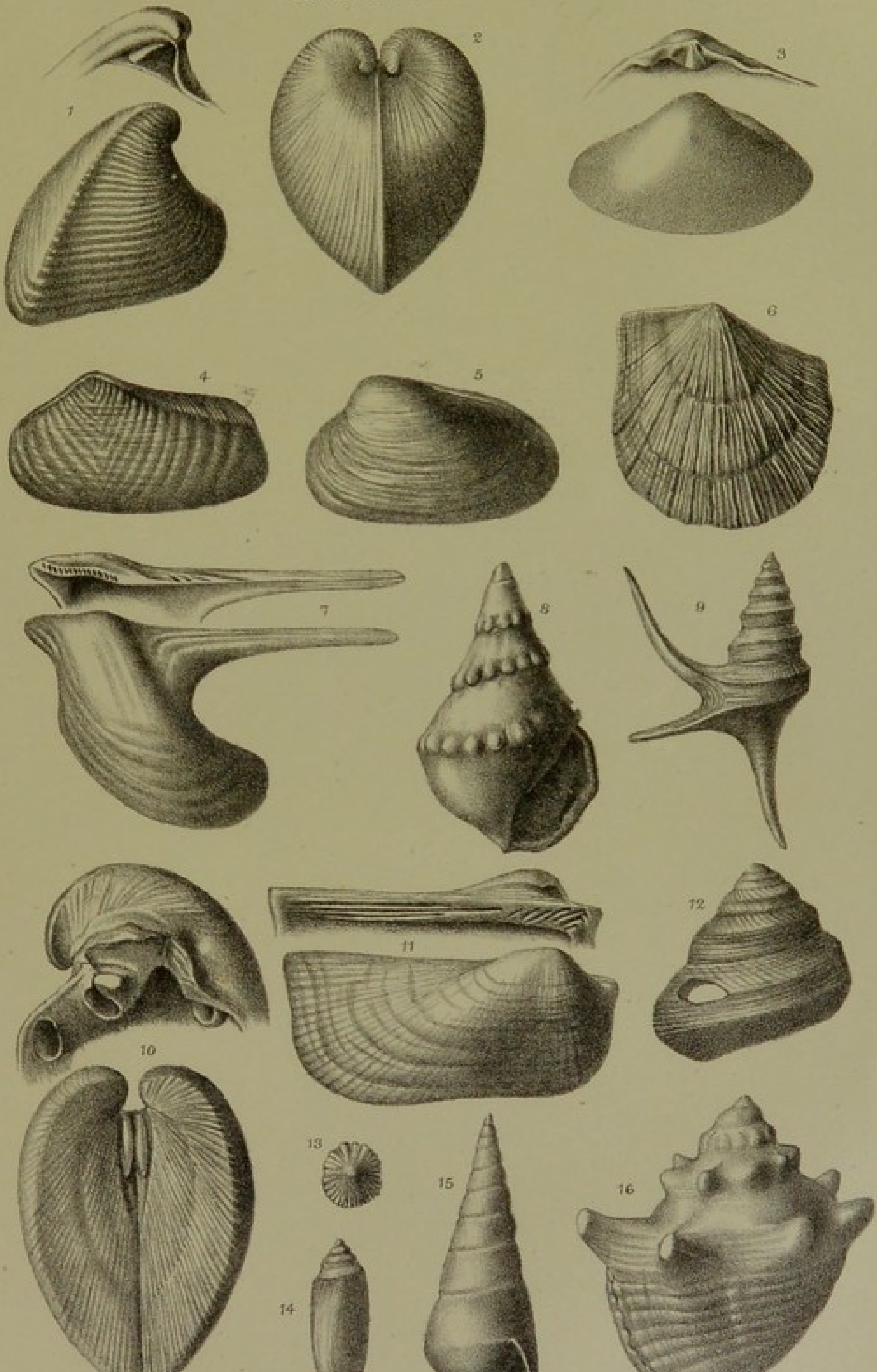
Lower and Middle Oolites.

1.	Opis trigonalis, *Sby.*	*Inferior Oolite.*
2.	Ceromya concentrica, *Sby.*	*Inferior Oolite to Cornbrash.*
3.	Tancredia donaciformis, *Lyc.*	*Inferior Oolite.*
4.	Goniomya v-scripta, *Sby.*	*Inferior Oolite to Cornbrash.*
5.	Gresslya abducta, *Phil.*	*Inferior Oolite to Great Oolite.*
6.	Hinnites velatus, *Goldf.*	*Inferior Oolite to Cornbrash.*
7.	Pteroperna costatula, *Deslong.*	*Inferior Oolite to Great Oolite.*
8.	Amberleya nodosa, *Buck.*	*Great Oolite.*
9.	Alaria trifida, *Phil.*	*Great Oolite to Coralline Oolite.*
10.	Pachyrisma grande, *Lyc. and Morr.* ...	*Great Oolite.*
11.	Macrodon Hirsonensis, *D'Arch.* ...	*Inferior and Great Oolite.*
12.	Trochotoma obtusa, *Lyc. and Morr.* ...	*Great Oolite.*
13.	Pileolus plicatus, *Sby.*	*Great Oolite.*
14.	Cylindrites bullatus, *Lyc. and Morr.* ...	*Great Oolite.*
15.	Nerinæa Voltzii, *Deslong.*	*Great Oolite.*
16.	Purpuroidea Morrisii, *Buvig.*	*Great Oolite.*

Plate IX.

MESOZOIC MOLLUSCA:- JURASSIC.

Lower & Middle Oolites.



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Prestwich's Geology, II. — Clarendon Press.

Hamites, Alaria, Chemnitzia, Ceromya, Trigonia, Cidaris, Isastræa, etc., and the lower, plants of the genera Palæozamia, Sphenopteris, Pecopteris, Cyclopteris, etc.[1] This flora is considered by Dr. Blanford to show relations with that of the Rájmahál group of India. (See Tables ii, iii, iv, v, and vi.)

[1] Stow in Quart. Journ. Geol. Soc., vol. xxvii. p. 497; Tate and Rupert Jones, *Ibid.* vol. xxiii. p. 144; and Rupert Jones, Brit. Assoc. Reports for 1884.

CHAPTER XVII.

THE NEOCOMIAN AND CRETACEOUS SERIES.

THE WEALDEN AND LOWER GREENSAND.

BREAK OF CONTINUITY. OLD ROCK DÉBRIS. MAIN DIVISIONS OF THE CRETACEOUS SERIES. THE WEALDEN GROUP. THE HASTINGS SANDS: GENERAL CHARACTERS; FRANT ROCKS; IRONSTONES; LIGNITE. THE WEALD CLAY: GENERAL CHARACTERS; ORGANIC REMAINS; CYCADS; IGUANODON AND HYLÆOSAURUS. OTHER WEALDEN BEDS. ISLE OF WIGHT. BOULOGNE. BELGIUM; THE AACHENIAN SERIES; ENTIRE SKELETONS OF IGUANODONS. HANOVER. PUNFIELD BEDS. NORTHERN LAND. SOUTHERN SEAS. SPEETON CLAY. THE LOWER GREENSAND. SUBSIDING AREAS. DISCORDANT STRATIFICATION. SEEND. CULHAM. THE POTTON DRIFT. GENERAL STRUCTURE: FOLKESTONE BEDS; SANDGATE BEDS; HYTHE BEDS; ATHERFIELD CLAY. BUILDING-STONES. MINERALS. ORGANIC REMAINS. THE FARINGDON BEDS. ABNORMAL CONDITIONS. DERIVED FOSSILS. TEALBY BEDS.

Break of Continuity. It is difficult to say whether, in the South of England, there is any unconformity between the Purbeck and the Wealden, or whether they pass one into the other. While some geologists have grouped the Purbeck with the Oolites, others have placed it with the Wealden. Certainly in many places there is no perceptible break between the two, and there are many species in common. Nevertheless, it is evident that some important and widespread changes in the physiography of the European area took place at the close of the Purbeck period. Certain marine areas were converted into fresh-water and estuarine areas—others emerged altogether, as in South-east Belgium; while, on the contrary, the South-western area of the Ardennes was submerged, and deposits of Wealden age (Aachenian) were spread over the sunk palæozoic rocks of Hainaut. Oolitic, as well as palæozoic areas, suffered degradation, for the Wealden strata sometimes contain rolled fragments of Oolitic Ammonites and other fossils, showing that they were partly formed from the waste of Jurassic strata, while some of the grits and fine conglomerates are formed from the waste of palæozoic rocks. A good instance of such waste occurs in the thinly developed Wealden beds of the Boulonnais, where there is a pebbly bed five to fifteen feet thick, composed entirely of sub-angular fragments of white quartz, derived evidently from the quartz veins of palæozoic rocks, which come to the surface in the north of that district on the prolongation of the axis of the Ardennes.

In Germany the setting in of the Neocomian period is sometimes marked by great beds of conglomerate (the Hils Conglomerate) at the base of deposits of this age.

The Greater Divisions. In the South of England the Cretaceous series consists broadly of the following divisions :—

Upper Cretaceous	Chalk	1200 feet.
	Upper Greensand	50 "
	Gault	150 "
Lower Cretaceous (Neocomian)	Lower Greensand, or Upper Neocomian	600 "
	Wealden, or Lower Neocomian ...	1500 "

THE WEALDEN GROUP (LOWER NEOCOMIAN).

These strata occupy those portions of Kent, Sussex, and Surrey, known as 'the Weald,' lying between the North and South Downs, or rather between the ranges of the Lower Greensand, which run parallel to and within the line of Downs. The strata are of fresh-water and estuarine origin, and consist of two divisions—the upper being 'The Weald Clay,' and the lower 'The Hastings Sands.'

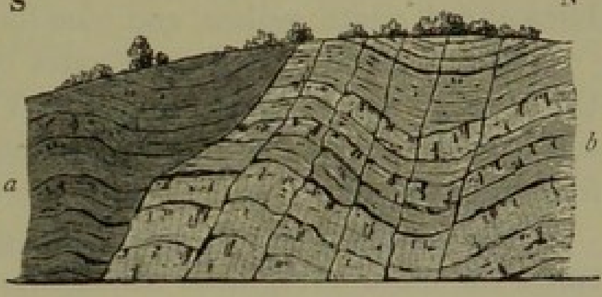

FIG. 135. *Section on the Railway one mile S. of Tunbridge. The Tunbridge-Wells Sandstone (b) is here brought up by a fault against the Weald Clay (a).*

We are indebted to Dr. Mantell[1] for the earliest account of the geology of the Wealden district, and for the discovery of the great Reptilian remains in Tilgate Forest. Dr. Fitton[2] added largely to our knowledge of the strata and the fossils of the Wealden series, both in Kent and in the Isle of Wight. The more recent work of the 'Geological Survey,' the results of which are embodied in the separate memoir by Mr. Topley[3], gives a very exhaustive account of the stratigraphical details and physical characters of this area. According to these later researches :—

[1] 'Geology of Sussex,' 1827; 'Geology of the South-East of England,' 1833; 'Wonders of Geology,' 1848; and 'Medals of Creation,' 1854.

[2] 'Observations on the Strata between the Chalk and the Oxford Oolite in the South-East of England;' Trans. Geol. Soc., 2nd ser., 1836, vol. iv. p. 103, etc., and 'Geology of Hastings,' 1833.

[3] 'Geology of the Weald,' 1875.

'The Hastings Sands,' or lower division, has been subdivided as under in descending order :—

1.	*Tunbridge-Wells Sands*, consisting of soft sandstones, often ferruginous, and of the subordinate clays of Cuckfield and East Grinstead	200 feet.
2.	*Wadhurst Clays*,—a series of clay-beds frequently mottled, with thin seams of shelly limestones, and of ironstone	150 ,,
3.	*Ashdown Sands*,—soft sandstones, with subordinate beds of clay and ironstone ...	150 ,,
4.	*Fairlight Clays*, consisting of thick strata of mottled red, white, and blue clays, with subordinate beds of limestone and sandstone	360 ,,

Hastings Sands. The general characters of this division of the Wealden strata may be observed in the neighbourhood of Tunbridge Wells, of Wadhurst, and of Hastings. In the first-named district the massive soft sandstones of the High Rocks, Frant, constitute a marked feature in the series. Some portions of these rocks are so little consolidated that they disintegrate rapidly on exposure to the atmosphere, and return to the condition of the original muddy sand of which they were formed, like the mudstones of the Ludlow series. The frequent presence of iron in the sandstones often renders the underground waters slightly chalybeate, and it is to this cause that the chalybeate springs of Tunbridge Wells are due.

Thick beds of unfossiliferous mottled clays form, in the neighbourhood of Wadhurst, a district still to a great extent covered by woods. A good example of these clays is exhibited in the cliffs and on the shore at Bulverhythe Point, about one mile west of St. Leonards, where their vivid hues of red, white, yellow, and blue form a striking picture at low tide.

The thinner-bedded sandstones of the third stage are well exposed in the cliffs to the east of Hastings. They often show finely ripple-marked surfaces, and abound in indistinct plant-débris with casts of Cyclas and other fresh-water shells. No. 4 is well shown at Goldbury Point.

The Iron-ore of the Wealden is generally a clay-ironstone, but sometimes the more ferruginous sandstones have been worked. The former lies in bands in some of the Wadhurst and Ashdown clays. These ores were for many centuries—dating as far back as the Roman occupation or even earlier—worked for the manufacture of iron. Some of the furnaces were not 'blown out' until the middle of the last century, when, owing to the increasing scarcity of wood and the competition of coal-made iron, the works were abandoned.

No true coal is found in the Weald, but beds of Lignite are not uncommon; some of them are two or three feet thick. Several such beds may be seen in the low cliffs at Bexhill, two to three miles west of St. Leonards. It was the presence of these beds, together with dark shales somewhat like coal-shales, which led, at the beginning of this century, to the expensive and abortive search for coal at Bexhill[1].

The Weald Clay, which overlies the Hastings Sands, has a thickness

[1] See Dixon's 'Geology of Sussex,' 1878 edited by Prof. T. Rupert Jones, p. 139.

of about 1000 to 1500 feet, and consists chiefly of blueish-grey clays, marls, and shales, containing a few subordinate layers of shelly limestone and of sandstone, and nodules of clay-ironstone. It is in the valley formed by these clays that the South-Eastern Railway runs from Red Hill to Ashford. The sections in this district are few, though temporary marl-pits (with a few thin limestones) are numerous. Some good 'pottery' clay is worked at Pluckley.

At Stammerham, near Horsham, the thin fissile and shelly calcareous rock, used for roofing, is covered layer after layer with ripple-marks as distinct as those on existing strands and sand-banks. Some of the more compact and thicker beds, which are full of a species of *Paludina*, were formerly much worked near Petworth, Bethersden, and other places, as a marble for interior decoration.

Organic Remains. The fossils of the Weald Clay and the Hastings Sands are on the whole alike, and may be taken together.

Plants. Angiospermous Dicotyledons are found in the Cretaceous strata of the Continent and of North America, but as yet only Gymnosperms and Cryptogams have been discovered in beds of this age in England. These have been described by Mr. Carruthers, F.R.S., from whose description [1] the following remarks are extracted.

Wood, foliage, and cones of *Coniferæ* have been found in different beds, together with great trunks of Pine-wood converted into a brittle jet or replaced by calcite, when all the minute details of their structure are beautifully preserved. They show all the characters of the wood of the existing pines. At Brook Point, in the Isle of Wight, single flattened leaves of an Abies-like Pine, and at Hastings branches clothed with short acicular leaves, have been found. They are referred to *Widdringtonites Kurrianus*, Endl., though their affinity with the South-African conifer Widdringtonia is very doubtful. A fragment of a branch from Tilgate Forest resembles *Cryptomerites*, and another from Hastings is like that of a Yew.

The small cone found in a hard grit in Ashdown Forest, and figured by Fitton, is now decided to be not only a true Araucaria, but also to belong to the Eutacta section of the genus, the species of which now live in Australia.

The most striking feature, however, of this Flora is in the species of *Cycadeæ*, which represent not only the existing tribes, but also a genus which did not survive beyond the Lower-Cretaceous period. In one specimen (*Dioönites Brongniarti*), from Heaver's Wood Common near Reigate, described by Mantell, the attachment of the rigid pinnæ indicates a relation to the existing American genus Dioön. In the Wealden of Brook Point numerous cones of *Cycadeæ* occur. They are converted into

[1] Dixon, *Op. cit.*, 1878, pp. 277–282.

an impure jet and are difficult to preserve. Mr. Carruthers considers that they are true Cycadean fruits, and possibly referable to seven species, for which he proposes the generic name *Cycadeostrobus*.

The most remarkable Cycadean remains are however the casts preserved in the Tilgate beds. These trunks (*Bucklandia*), of which two species are known, are elongated cylindrical stems covered with rhomboidal scars as in the stems of the living *Cycas circinalis*, L. Amorphous casts of oval nuts or seeds, like the seeds of Cycads, occur in the same beds. A stem from the Wealden of the Isle of Wight has the arrangement of the leaves and scales like that in the existing African genus *Encephalartos*. The extinct genus, *Bennettites*, is characterised by the nature of its fleshy fruit, which was either borne on shortened axes among the leaf-bases, or on somewhat elongated branches beyond them.

At Pounceford and some other localities, the remains of an *Equisetum* are not infrequent. It was a large plant resembling the living *E. maximum*. There are also several species of Ferns, but with few exceptions they are badly preserved. The *Endogenites erosa*, Mant., is probably a portion of an arborescent Fern. The following are some of the more characteristic Wealden plants :—

Coniferæ.

Pinites Linkii, *Rœm.*
„ Dunkeri, *Carr.*
Widdringtonites Kurrianus, *Endl.*

Filices.

Sphenopteris Mantelli, *Brongn.*
„ gracilis, *Fitt.*
Laccopteris Gœpperti, *Schimp.*

Cycadeæ.

Dioönites Brongniarti, *Mant.*
Cycadeostrobus (*genus*, *Carr.*).
Bucklandia anomala, *Presl.* (Clathraria Lyellii.).
Fittonia squamata, *Carr.*
Bennettites Saxbyanus, *Carr.*

Equisetaceæ.

Equisetites Lyellii, *Mant.*

Crustacea. The Wealden strata contain no large Crustacea, but minute Entomostraca abound. Professor Rupert Jones states that although many of these have been referred to Cypris, it is very doubtful if any of them belong to that genus; in all probability the majority belong rather to the Cytheridæ than to the Cypridæ. As a matter of convenience, Bosquet's generic name of *Cypridea* is adopted. A common species in the Wealden is *Cypridea Valdensis*, Sby.; besides which there are,—*C. Austeni*, Jones, *C. spinigera*, Sby., and *Metacypris Fittoni*, Mant. The phyllopodous *Estheria elliptica* (var. *subquadrata*, Dunk.) abounds at Bulverhythe, and has been found also east of Hastings and at Tunbridge Wells.

Mollusca. There is an almost total absence of marine genera, while a few species of fresh-water genera abound in some of the beds. They are generally however badly preserved,—the Paludinæ are mostly incorporated in the body of the thin impure limestones :—

Cyrena parva, Sby.
„ media, *Sby.*
„ angulata, *Sby.*
„ Valdensis, *Mant.*

Melanopsis attenuata, *Sby.*
Neritina Fittoni, *Mant.*
Paludina vivipara, *Sby.*
„ Sussexiensis, *Mant.*

Fishes. These are sufficiently characteristic, and are chiefly referable to Ganoids and Placoids. The *Lepidotus*, a Ganoid fish with bright lozenge-shaped scales, and nail-headed teeth, is allied to the Gar-fish of the American lakes. Of the fifteen species of fishes the most common are:—

Lepidotus Mantelli, *Ag.*	Hybodus dubius, *Ag.*
„ Fittoni, *Ag.*	Pycnodus Mantelli, *Ag.*

Reptiles. The Reptiles of the Wealden are numerous and very remarkable. The two great and distinguishing Wealden genera are the *Iguanodon* and the *Hylæosaurus*. The former, so named by Dr. Mantell from having teeth like the small Iguana of South America, was a colossal lizard-like Reptile, feeding on vegetables, and of a length estimated to have been from between 25 to 30 feet. Its bones are next in size to those of the gigantic Oxford *Cetiosaurus*, the femur measuring four to five feet in length. Considering the enormous size of the animal, the teeth are extremely small, not more than one or two inches long. They are very easily recognised from their peculiar shape, being broad, flat, and marginally notched; and they often have the crown worn down, as usual with vegetable-feeders. The animal probably had a beak-like snout, together with certain other structural affinities with birds.

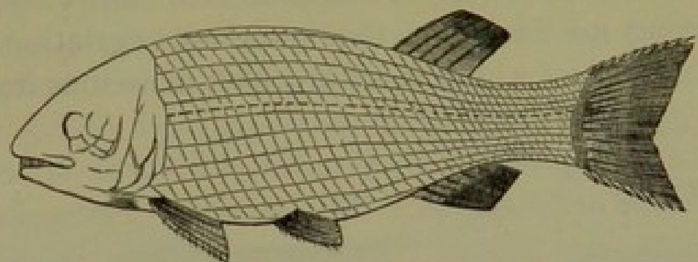

FIG. 136. *Lepidotus Fittoni*, Ag.

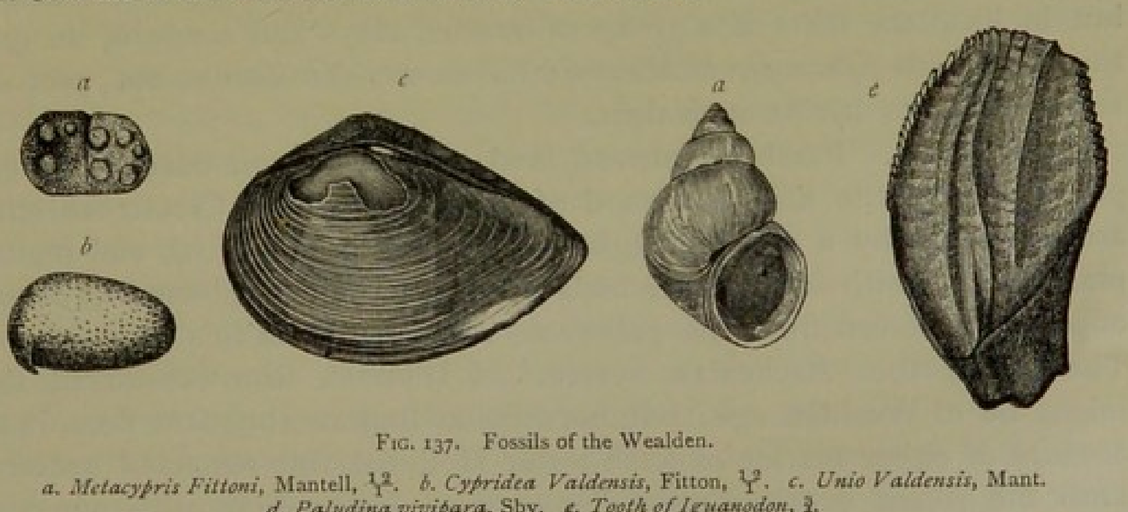

FIG. 137. Fossils of the Wealden.

a. Metacypris Fittoni, Mantell, $\frac{12}{1}$. *b. Cypridea Valdensis*, Fitton, $\frac{12}{1}$. *c. Unio Valdensis*, Mant. *d. Paludina vivipara*, Sby. *e. Tooth of Iguanodon*, $\frac{2}{3}$.

Some large tridactyle impressions on the Wealden strata at Hastings and Swanage have been referred to the prints of the hind feet of Iguanodon,—the creature probably walking at times with its fore-legs raised. With the exception of the one specimen from the Kimmeridge Clay the *Iguanodon* is an exclusively Cretaceous genus.

The other great Wealden reptile, the *Hylæosaurus*, is conjectured to have been about 25 feet long, and is remarkable for its enormous dermal bony spines, supporting a long defensive crest along the back. The teeth, again, are relatively small, and indicate a mixed or vegetable rather than a carnivorous diet. The skin was defended by sub-circular bony scales. Together with these exclusively Cretaceous genera, occurs the Oolitic genus of Dinosaur—the *Megalosaurus*; but the species are different.

Amongst the other Reptilian remains of the Wealden are turtles and a crocodile. With the exception of the carnivorous *Megalosaurus*, the Dinosaurs, or extinct land lizards of the Wealden, were all vegetable-feeders, living no doubt on the luxuriant vegetation of Cycads, Equisetaceæ, and Conifers, of which there are such numerous fragmentary vestiges.

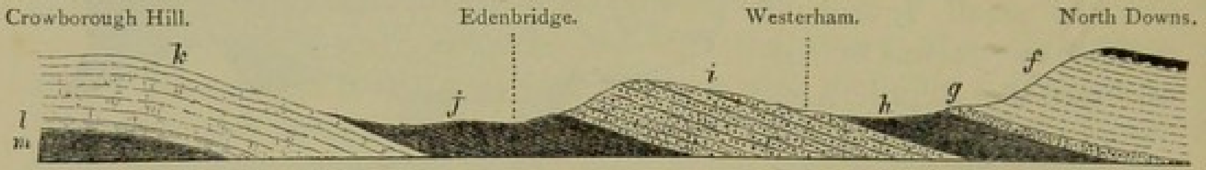

Fig. 138. Diagram-Section of the Wealden Strata from Crowborough Hill through Westerham to the North Downs.
f. Chalk. g. Upper Greensand. h. Gault. i. Lower Greensand. j. Weald Clay. k. Hastings Sands. l. Purbeck Beds. m. Kimmeridge Clay (unconformable).

Other Wealden Beds. Wealden strata occur at the back of the Isle of Wight (Sandown and Brook) and at Swanage. The Ironsands at Shotover are also probably of this date. Those of the Boulonnais would seem to mark the southern boundary of the old river-delta; for in the 'Pays de Bray,' 70 miles further south, the sequence, which is complete from the Kimmeridge Clay to the Chalk, shows no fresh-water Wealden; but in its place there is a group of mottled clays and sands, of no great thickness, with *Sphenopteris Mantelli*, *Cardium sub-hillanum*, etc., probably representing its marine equivalent.

Belgium. Further eastward, land and fresh-water conditions again prevailed. In the neighbourhood of Mons, the Upper Cretaceous strata are underlain by a series of light-coloured sands and grits, and mottled plastic clays, with subordinate beds of limonite and conglomerates formed of pebbles derived from the palæozoic rocks on which this series reposes. These form the 'Aachenian System' of Dumont, who considered they might be of Wealden age; but, notwithstanding an abundant flora, in the absence of either marine or fresh-water Mollusca, this remained uncertain until the recent extraordinary discovery of Iguanodons, with numerous fishes, land and fresh-water turtles, and plants of Wealden species, removed all doubts on the subject.

The Aachenian beds occupy a depression of small superficial area, but probably not less than 700 to 800 feet in depth, in the Coal-measures of Hainaut, filling apparently a steep valley running east and west. With this are connected deep narrow gorges with precipitous if not perpendicular sides, branching off at right angles through the surrounding coal-measures. In driving a gallery in the Colliery of Bernissart, the miners came at a depth of 1056 feet, and 726 feet below the top of the Coal-measures, upon one of these old ravines. For the first 30 feet they passed through Coal-measure débris, and they then came to stratified seams of fine sand and clay, lying at first at a steep angle, and gradually becoming nearly horizontal. In these beds there were found, at slightly different levels, the skeletons of five adult Iguanodons, with the bones, which were exceedingly fragile, all in place, and showing the reptiles to have been entombed entire and sprawling on their stomachs. With these were found an Emys and a Trionyx, a large number (above 100) of fishes in a remarkable state of preservation, together with numerous plants[1].

The Iguanodons vary in length from about 15 to 30 feet, the largest being *I. Ma telli* of the Weald. Amongst the fishes are *Lepidotus Mantelli*, and among the plants, *Sphenopteris Roemeri*. M. Coemans has shown that the plants are such as would flourish in a damp marshy soil, while the fishes show that those swamps were occasionally flooded and submerged. The huge reptiles attracted to these marsh-lands by the luxuriant vegetation, seem to have been swamped from time to time, and have thus come down to us in the wonderful state of preservation, of which their skeletons—now restored and put up with great skill in the Brussels Museum—are an admirable illustration.

Hanover. The only other group of fresh-water Wealden on the Continent occurs in Hanover. There, as in England, it consists of two divisions—the lower, sandy (sandstones of the Deister), and the upper, argillaceous (clays of Hils). These strata overlie conformably the Purbeck series, and pass transgressively over palæozoic rocks. The lower division, in places, passes down into or is underlain by a conglomerate of old-rock pebbles (conglomerate of Hils). Intercalated also in the Deister sandstone are fifteen beds of workable bituminous coal. Some of these beds are from three to four feet thick, and are formed of the usual Wealden Coniferous trees, Cycads, and Ferns, amongst which are *Sphenopteris Mantelli*, *Pinites Dunkeri*, etc. Other fossils of the English Wealden, such as *Cypridea Valdensis*, *Metacypris Fittoni*, *Unio Valdensis*, *Paludina vivipara*, together with species of Lepidotus, Sphærodus, etc., also occur.

Punfield Formation. In the cliffs east of Swanage there is a series of sand and clay beds, containing marine shells, noticed some years ago by the late Mr. Godwin-Austen, and which have more recently been shown by Professor Judd to be synchronous with the upper part of the Wealden, and have been termed by him the 'Punfield Formation.'

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[1] See M. Dupont's account of this discovery in the 'Bull. de l'Acad. Roy. de Belgique,' 2ᵉ sér., vol. xli. p. 387; 1878.

These beds are important, inasmuch as the Wealden beds of the South of England contain, with few exceptions (Ostrea in the Ashburnham beds), only fresh-water shells, and therefore offer no exact term of comparison with the marine portion of either the Cretaceous or the Oolitic Series. Professor Judd has now ascertained that these Punfield beds contain marine shells of the same species as well-known Lower-Neocomian fossils of the continent, such as,—

Modiola Giffreana, *Pictet et Roux.*
Cerithium Vilanovæ, *De Verneuil et De Lorière.*
Exogyra Boussingaulti, *D'Orb.*
Corbula striatula, *Sby.*
Ammonites Deshayesii, *Leym.*
Vicarya Lujani, *De Verneuil et Collomb.*
Isocardia nasuta, *H. Coquand.*
Cardium subhillanum, *Leym.*

This gives reason to suppose that the Wealden strata are synchronous with the Lower-Neocomian strata of Switzerland and other parts of the Continent; for although we have in the Lower Greensand a marine representative of the Upper-Neocomian beds, the great lower marine series, so largely developed in Switzerland and Savoy, are wanting in this country. M. Marcou recognised some years ago one of the Wealden fishes in the Neocomian beds of the Jura. The *Corbula elata* of the Purbeck is also found in the Swiss Neocomian.

It would seem therefore that while the early Neocomian Sea spread over a great part of central and southern Europe, a large continental land existed in more northern latitudes; and that through this land a great river flowed westward and southward unto an estuary placed in what is now the south-east of England, and that another such river débouched in the Hanoverian area. Living on those lands were the great Dinosaurian reptiles whose carcases, together with the remains of a varied land vegetation, were swept down by the floods and entombed in the sediments of the old rivers, together with their fishes and fresh-water shells.

The Speeton Clay (in part). On the coast between Flamborough Head and Scarborough, the cliffs consist partly of beds of dark clays with cement-stone, and shales, forming the series (some 800 to 1000 feet thick) known as the Speeton Clay, the geological position of which was long uncertain. Professor Judd has now shown that these are really a consecutive series of strata of very similar petrological character, conformable throughout, and ranging from the top of the Coralline Oolite to the base of the Upper-Cretaceous Series, so that it in fact consists of strata of Kimmeridge, Portland, and Neocomian age.

The Neocomian section is divisible into three groups, the lower being considered to be the marine equivalent of the Wealden of Kent. It contains 42 species of fossils, of which *Ammonites Astierianus*, *Ancyloceras Duvalii*, *Exogyra Couloni*, *Toxaster complanatus*, and others serve to establish its correlation with the marine equivalent of the Wealden on the Continent.

The upper division contains fossils common to the Lower Greensand of the South of England, where it overlies the Wealden beds, so that the relative position of the two is clearly determined.

THE LOWER GREENSAND (UPPER NEOCOMIAN).

In the Oolitic series, we had no great break to notice, either in the sequence of animal life, or in the order of stratification. The several formations follow one another in regular order, and without any marked unconformity in superposition. There are indications of many minor movements, but of none on a scale to produce disruption of the strata and marked unconformity.

On the whole, the seas in which were deposited the various Oolitic strata were shallow, though often nearly free from land débris. From time to time they became deeper by subsidence, and then were deposited the several argillaceous formations, such as the Oxford and Kimmeridge Clays. At other times, the sea-bed was raised to the tide-level, and then we have those evidences of littoral and shore conditions which occur on the top of the Inferior Oolite, in the Great Oolite, and the Coralline Oolite, and which, at the close of the Portland period, displaced altogether the Oolitic sea. But, on the whole, these were minor movements of slow subsidence and elevation, and, except the last, were not of a permanent character.

Subsiding Areas. In the Neocomian we reach a point in the geological sequence, when other great continental changes supervened. At the close of the Lower Neocomian there was a gradual submergence and great extension of the Neocomian Seas. This was productive in England of a general slight unconformity and overlap, such as that which at Seend, near Devizes, again at Faringdon and Potton, brings the Lower Greensand (in the absence of the Wealden and Portland strata) over the Kimmeridge Clay. At Seend this is shown in the slightly denuded surface, and the drilling of the exposed septaria by boring shells; while the denudation of the Jurassic and older strata is proved at Faringdon by the numerous derived and worn fossils of the Kimmeridge Clay, Coral Rag, and Oxford Clay, together with the pebbles of the various palæozoic rocks, there contained in the Lower Greensand. At Culham, near Abingdon, and Cumnor, near Oxford, the Lower Greensand again rests on the Kimmeridge Clay, without the intervention of the Portland and Wealden beds. Further westward the Lower Greensand extends over part of the Oolitic and Triassic area of Dorset and Devon.

The phosphatic-nodule bed of the Lower Greensand at Potton, in Bedfordshire, affords a striking instance of the wear of the Jurassic rocks that took place at this period, for amongst the derived fossils there are a large number of rolled and water-worn specimens of Saurian teeth and bones, fragments of Ammonites, Terebratulæ, and other organic remains, derived from the several more or less distant Oolitic strata.

General Structure. The divisions of the Lower Greensand in Kent, adopted by the Geological Survey, are :—

Folkestone Beds	150 feet.
Sandgate Beds...	90 ,,
Hythe Beds (including the Kentish Rag)	200 ,,
Atherfield Clay	40 ,,

It is a very variable Formation, attaining a thickness of 800 feet in the Isle of Wight, then thinning off as it ranges westward and north-westward over older strata into Dorsetshire and Wiltshire.

An instructive section of the Lower Greensand is exposed in the cliffs between Eastware Bay near Folkestone, and Hythe. The strata extend

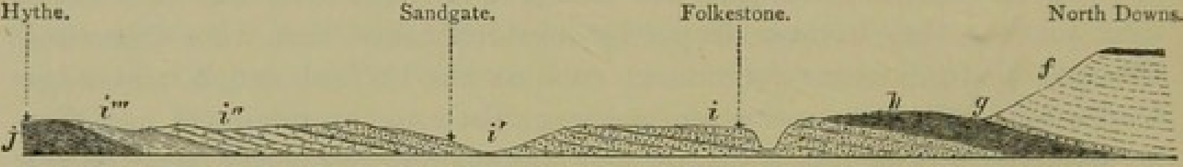

Fig. 139. Generalised section from Folkestone to Hythe.

f. Chalk. *g. Upper Greensand.* *h. Gault.*
i. Folkestone beds. *i'. Sandgate beds.* *i''. Hythe beds.* *i'''. Atherfield Clay.* } *Lower Greensand.*
j. Weald Clay.

thence in a range of hills parallel with the North Downs, by Maidstone and Reigate, to near Farnham, then pass round by Petersfield and Midhurst, near to the coast at Pevensey. In the Isle of Wight they form the cliffs from Sandown to Brook. North of London the Lower Greensand ranges, with occasional breaks and considerable variations of lithological characters, parallel with the Chalk hills through Bedfordshire (Woburn, Leighton), Cambridgeshire (Sandy, Potton, Upware), and Lincolnshire, to the Yorkshire coast, near Filey.

Atherfield Clay. This is an irregular bed of dark clay, with calcareous bands, varying from 20 to 70 feet in thickness. The best sections are on the coast. Inland there are few. *Perna Mulleti* and *Exogyra sinuata* are characteristic fossils.

Hythe Beds. These consist of sands, light grey calcareous sandstones, and occasional seams of chert. The sandstones are largely worked at Maidstone and elsewhere as a building stone known under the name of Kentish Rag. Though it can only be chiselled into rough faces, it is valued for its hardness and durability. The railway-cutting at Sevenoaks exposes a good section of these beds, but the stone is there so soft and sandy, that it is not much used. *Trigonia caudata* and *Gervillia aviculoides* are amongst the few fossils.

Sandgate Beds. These beds are frequently separated from the Hythe beds by a fossiliferous basement-bed of pebbles and phosphatic nodules. Green sands, soft sandstones, and clays predominate in this division, which is the least persistent of the series. It is well seen in the cliffs between Folkestone and Sandgate. Inland it becomes less argillaceous.

The Bargate stone which is worked around Godalming belongs either to the top of the Sandgate beds, or to the base of the Folkestone beds. It is to the same horizon also that the bed of Fuller's-Earth, worked at Nutfield, near Reigate, belongs. This is a clay containing a larger proportion of silica than ordinary clays, and which when placed in water, instead of forming a plastic mass, falls to pieces. It is used by fullers in the manufacture of cloth, as it possesses the property of taking grease out of woollen fabrics. Sulphate of barytes in long yellow crystals is found associated with this clay.

Folkestone Beds. At Folkestone, the upper division consists of a series of light-coloured quartzose sands, often full of Sponge spicules, with seams of chert and beds of grit, together about 120 feet thick. In Mid Kent the seams of chert become more important. They cap the surface of many of the hills between Maidstone and Sevenoaks, and owing to their having been shattered *in situ* into small fragments, they are much used for gravel. At Oldbury Hill, near Ightham, this series is well exhibited and contains some peculiar green, red, and yellow varieties of chert, which are in consequence easily recognisable in the Thames Valley Drift.

This upper division becomes, as it ranges westward, much more ferruginous, and the thick sands contain subordinate seams and thin irregular plates and tabular layers of compact iron-sandstone and ironstone-grit. This is especially the case in the sand-hills around Haslemere and Petersfield. At the base of the Greensand at Seend, and belonging to this zone, there is a bed of pisolitic iron-ore 10 to 12 feet thick, and so loose as to be worked with a spade.

The Lower Greensand of the Isle of Wight has been described in great detail by Dr. Fitton and Edward Forbes. It there attains a much greater thickness, and is much richer in organic remains than in Kent, and presents also very different petrological characters. The fine cliff-section from Shanklin to Atherfield is classic ground.

Organic Remains. The organic remains of the Lower Greensand are, with the exception of some beds of the Kentish Rag in which Terebratulæ and Exogyræ are abundant, generally scarce in the arenaceous beds of Kent, Surrey, and Sussex, but they abound in some of the calcareous and nodular beds of the Isle of Wight. The great characteristic Mesozoic families of Cephalopods, Brachiopods, and Reptiles are continued up into strata of this period, but with a marked change in their distribution. We have further to note in the Neocomian series not only the disappearance of a number of genera, but also the introduction of many new forms, and an entire change in all the species.

Plants[1]. The Flora is very similar to that of the Wealden. The *Pinites Sussexiensis* is a true pine. The cones found in this formation are of much interest. Four of them, of which three are from the Kentish Rag of Maidstone, belong to the Cedar. A beautiful and perfect cone from Shanklin, the *Pinites Leckenbyi*, also resembles in size and form the cones of the *Pinus cedrus*, L. At the present day the Cedar is represented by only two species—the Cedar of Lebanon and the Deodar of India. Some fine cones have also been found in the neighbourhood of Leighton in Buckinghamshire.

In the sands of Potton, a cylindrical stem (*Yatesia Morrisii*) covered with short tumid leaf-bases, and allied to the Zamia group of living Cycadeæ, has been found; with also a small species of *Mantellia* (*M. inclusa*, Carr.).

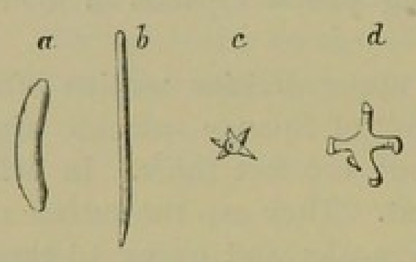

FIG. 140. Lower Greensand Spicula. *a. Reniera obtusa*, $\frac{40}{1}$. *b. Axinella gracilis*, $\frac{40}{1}$. *c. Geodites*, sp. $\frac{20}{1}$. *d. Mastosia neocomiensis*, $\frac{20}{1}$.

Sponges. Calcareous Sponges are largely represented in the Faringdon and Upware beds; and in the Folkestone beds of Haslemere there are thin beds almost entirely composed of the spicules of siliceous sponges. The form of the sponge is rarely preserved, but in a pit near the gas-works of Sevenoaks there is a bed full of loose spicula and whole sponges.

FIG. 140*. *e. Cythereis quadrilatera* (Roemer), $\frac{12}{1}$.

Crustacea. The *Astacus Vectensis* is a common fossil in some of the Isle of Wight beds (the Lobster-beds), but otherwise crustacean remains are rare. Entomostraca are not numerous. *Cythereis quadrilatera* occurs, but it is more common in the Gault and Lower Chalk. *Polyzoa.* These are almost entirely confined to the remarkable local deposit of Faringdon. Phillips mentions 46 species from that locality.

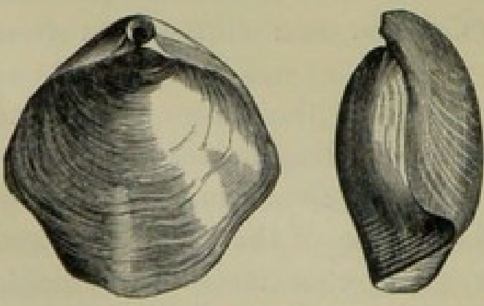
FIG. 140**. *Terebratula sella*, Sby.

Brachiopods. The species of *Rhynchonella* (*Rh. Gibsiana*) and *Terebratula* (*T. sella*) of the Lower Cretaceous beds are no longer of the Oolitic type, but more resemble the living species of *Rhynchonella psittacea* and *Terebratula* (Waldhemia) *vitrea*. A new genus of Brachiopods first makes its appearance—the *Terebratella*—of which the *T. Menardi* is a common form.

Bivalve Mollusca. Some of the Mollusca present very characteristic forms. Among the most common bivalves are *Exogyra sinuata*, *Cardium Hillanum*, *Cyprina angulata*, *Diceras Lons-*

[1] See Carruthers, in Dixon's 'Geology of Sussex,' 2nd Edit., pp. 279-281.

dalei, Gervillia anceps, Myacites plicata, Perna Mulleti, Trigonia caudata, T. alæformis.

Univalve Mollusca. Actæon marginatus, Natica rotundata, Cerithium Neocomiense, Pleurotomaria gigantea.

Cephalopods. Ammonites Deshaysii, A. noricus, Nautilus plicatus, Crioceras Duvallii, Ancyloceras (Scaphites) gigas, A. Mathesonianum.

Fishes. They are few and present few new features. Hybodus is a common form.

Reptiles. Remains of the *Iguanodon Mantelli* are found in the ragstone at Maidstone, and Bargate stone near Guildford, and of *Ichthyosaurus camplylodon* in the Sandgate beds.

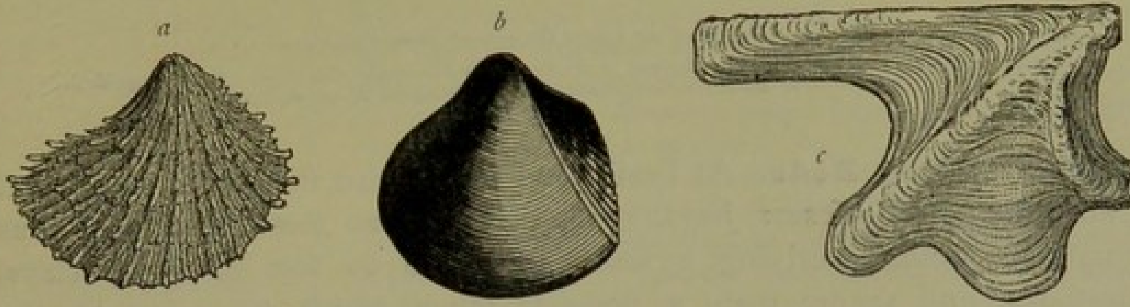

FIG. 141. Mollusca of the Lower Greensand.
a. Plicatula placunea, Lam. *b. Cardium Hillanum*, Sby. *c. Perna Mulleti*, Desh.

The Faringdon Beds. These sands, which are supposed to be on the horizon of the Folkestone beds, possess a peculiar local character, only known in the neighbourhood of Faringdon. They form a thick bank of pebbly, ferruginous sands, partially consolidated, and full of Sponges of various species, of innumerable Polyzoa, generally fragmentary, of Echinoderms, together with a few species of Mollusca and Foraminifera, and a considerable number of derived fossils. The common species are:—

Amorphozoa. *Raphidonema* (Manon) *Faringdonense, R. macropora, Syropella* (Manon) *pulvinaria, Peronella Gillieroni, P. ramosa, Corynella* (Scyphia) *foraminosa, Tremacystia* (Verticillites) *anastomosans.*

Foraminifera. *Cristellaria*, etc.

Echinodermata. *Cidaris Faringdonensis, Diadema rotulare, Salenia Cardyi.*

Polyzoa. *Actinopora papyracea, Alecto Calypso, Pustulopora pseudospiralis*; Ceriopora 5 sp., Diastopora 2 sp., Eutalophora 2 sp., Reptomulticana 2 sp., etc.

Of 26 derived fossils from Faringdon in the Oxford Museum, nine are from the Kimmeridge Clay, eight Coral Rag, four Oxford Clay, and five are indeterminable. The smaller pebbles consist in large part of white quartz: with these there is a number of various sizes of pebbles of quartzite, veinstone, jasper, slate, etc., derived from palæozoic rocks. It is probable that these latter formed the old land, now submerged beneath the Cretaceous and Tertiary strata, that stretched from the Ardennes to the Mendips, and constituted part of a continental area with a very much indented coast-line.

In Cambridgeshire and Norfolk the Lower Greensand forms a ferruginous rock, occasionally very fossiliferous, known as the "Carstone."

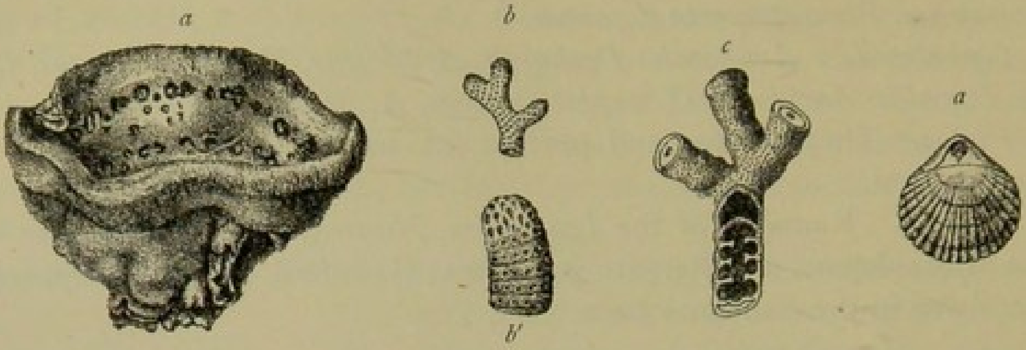

FIG. 142. Fossils of the Lower Greensand, from Faringdon.
a. *Raphidonema* (Manon) *macropora*, Sharpe. b. *Pustulopora pseudospiralis*, Mich. b'. *do.* magnified. c. *Verticillites anastomosans*, Mant. d. *Terebratella Menardi*, Lam.

The Tealby Beds. At Tealby, in Lincolnshire, the Lower Greensand is, according to Professor Judd, represented by 20 feet of unfossiliferous ferruginous sands overlying a series of 80 to 90 feet of sandy clays, limestones, and sands, with a peculiar fauna which he refers to the Middle Neocomian of Yorkshire. The fine *Pecten cinctus*, 9 to 12 inches in diameter, is there common. *Ancyloceras Duvallei*, *Belemnites lateralis*, *B. jaculum*, *Ammonites clypeiformis*, *Terebratula hippopus*, also occur; together with *Exogyra* (Gryphæa) *sinuata*, *Rhynchonella parvirostris*, etc. As they range southward these beds thin out.

In Yorkshire the upper and middle part of the Speeton Clay is, according to the same authority, the equivalent of the Lower Greensand of the South of England. It there consists of argillaceous strata 200 to 300 feet thick, with *Perna Mulleti*, *Terebratula sella*, *Ammonites Deshaysii*, etc. Ammonites abound in some of the beds. The cliff sections are generally much obscured.

Foreign Equivalents; France. At Wissant it is only the upper part (or the zone of *Ammonites mammillaris*) of the Folkestone beds that shows under the Gault. Further inland at Samer and Desvres the Folkestone Sands attain a greater thickness, but they contain few fossils. The lower members of the Lower Greensand are wanting there, as they are also in the other northern departments; they are, however, well developed in the Haute Marne, and are characterised by *Ammonites Milletianus*, *A. Deshaysii*, *Plicatula placunea*, *Ancyloceras Mathesonianum*, and other fossils of the Aptian proper which there overlies strata of Lower Neocomian age. The latter present the marine and fresh-water characters of both the Wealden and Swiss types, for the lower beds contain *Ostrea Couloni*, *Pteroceras pelagi*, etc., while in the upper division, beds containing species of Unio, Cyclas, Paludina, etc., with plant remains (Filices, Sequoia, Pinus, etc.), are interstratified with others containing *Ostrea Leymerei, Cardium Voltzi, Natica Cornueli,* etc.[1]

The Jura. It is not until we approach the Swiss area that the marine Neocomian attains its fuller development and more marked characters, and that the submergence of the Oolitic series became more general and effective. The strata in that area have been fully described by M. Marcou, Professors Desor, Renevier, and Jaccard[2], and other geologists, and have been subdivided in the French and Swiss Jura into the following groups:—

ALBIAN OR GAULT.	
Aptian including the Rhodonian of Renevier (50 to 100 feet).	Green and grey sands and sandstones, with *Epiaster polygonus, Plicatula placunea, Ostrea aquila, Janira Morrisi, Pteroceras pelagi, Heteraster oblongus, Hemicidaris clunifera,* etc.
Urgovian (80 to 200 feet).	White and grey limestones with subordinate oolitic and lumachelle beds. *Requienia (Diceras) ammonia, Radiolites Neocomiensis, Goniopygus peltatus, Pterocerus pelagi, Pygurus productus, Rhynchonella lata, Orbitolina lenticularis,* etc.
Upper Neocomian or Hauterivian (300 to 500 feet).	Yellow limestones (Neufchatel), and subordinate marls; blue and yellow marls (Hauterive); with *Cardium peregrinum, Terebratula Marcousana, T. diphyoides, Toxaster complanatus, Dysaster ovulum, Ostrea macroptera, O. Couloni, Perna Mulleti, Ammonites asterianus;* Sponges, etc.
Lower Neocomian or Valengian (150 to 200 feet).	Ochreous limestones with beds of pisolitic iron-ore, over white limestones and white and blue marls; with *Pygurus rostratus, Pholadomya Scheuchzeri, Terebrirostra Neocomiensis, Terebratula Valdensis, Strombus Sautieri (Natica leviathan,* Pict.), *Trigonia cincta,* etc.
PURBECKIAN.	

In the Valengian there are workable beds of limonite; and the limestones of the Upper Urgovian contain valuable deposits of *asphalt.* It is in these that the well-known works of the Val-de-Travers are situated. The source of the asphalt is not by sublimation from any underlying beds, for it is confined to a special zone, in which the limestone is impregnated with it. Its origin is attributed to the decomposition of the innumerable Requieniæ, Radiolites, and other fossils which abound in that rock[3].

English geologists place the Gault with the Chalk in the Upper Cretaceous Series, and the Lower Greensand in the Upper Neocomian; but many Continental geologists place both the Aptian and Urgovian in the same division as the Albian or Gault, and limit the Neocomian to the Hauterivian and Valengian groups. They also include the Upper Folkestone beds, with *Ammonites mammillaris,* in the Gault. Owing to the circumstance that, in the South-of-England area, land and fresh-water conditions prevailed during all the early (Wealden) part of this period, and of

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[1] 'Bull. Soc. Géol. France,' 3me sér., vol. i. p. 326; vol. ii. p. 371.

[2] *Op. cit.*, p. 144 *et seq.*

[3] The use of this asphalt is far from being a modern discovery, for the people of the lake-dwellings employed it as a cement to fix their arrow-heads.

the survival or the earlier setting in of certain species in some areas than in others, it becomes difficult to establish the exact correlation of the several minor subdivisions. Broadly they may be taken as under:—

France and Switzerland.	South of England.	Yorkshire and Lincolnshire.
Aptian and Urgovian.	Folkestone Beds (part). Sandgate Beds. Hythe Beds. Atherfield Clay.	The Speeton Clay and Tealby Beds.
Hauterivian and Valengian.	Punfield Beds. Weald Clay. Hastings Sands.	

Further southward the Lower-Cretaceous series assumes the Alpine type. Its lower divisions are represented by great masses of marls and limestones abounding in Cephalopods, and with the characteristic *Terebratula diphyoides*, *Pygurus rostratus*, *Pteroceras pelagi*, etc., overlain by compact Urgovian limestones with *Diceras ammonium*, *D. Lonsdalei*, *Orbitolina conoidea*, *Toxaster Collegnii*, etc., succeeded by less important Aptian beds with *Ammonites Milletanus*, *Ancyloceras Mathesoni*, *Plicatula placunea*, etc. The lower of these strata, which exhibit a marked pelagic facies, attain a thickness of some 3000 to 4000 feet.

The Aptian and Urgovian are well developed in the **Pyrenees** and the north of **Spain**, and near Bilbao they contain some valuable iron-ores; while in Eastern Spain (Aragon and Valencia) there are important coal-bearing strata of Urgonian and Neocomian age, between the latter of which and the Punfield beds Professor Judd has, on the evidence of organic remains, established close relations.

Massive Neocomian limestones occur in the central Apennines, and in the Alps of Lombardy. They further range through the Tyrol and into Bavaria. The marine beds of the Lower-Cretaceous series are, however, wanting in Northern Germany, where generally the Cenomanian (Quader-sandstein) rests directly and unconformably on Jurassic and other older rocks. The Neocomian and Albian reappear in Silesia, Poland, and the Carpathians, with some western European species of Ancyloceras, Ammonites (*A. Neocomiensis*), Belemnites (*B. minimus*), etc.

With respect to the extra-European beds of this age, it will be more convenient to take them, with the general range of the Cretaceous series in other parts of the world, at the end of the chapter on the Chalk.

CHAPTER XVIII.

THE UPPER CRETACEOUS STRATA.

THE GAULT AND UPPER GREENSAND.

BREAK IN SEQUENCE AFTER THE NEOCOMIAN. FURTHER SUBMERGENCE. TRANSGRESSIVE STRATIFICATION. MAIN DIVISIONS OF THE UPPER CRETACEOUS SERIES. THE GAULT. ITS PALÆONTOLOGICAL ZONES; RANGE; AND THICKNESS. ORGANIC REMAINS; VARIABILITY OF CONDITIONS. RED CHALK OF HUNSTANTON AND ITS RANGE. THE GREENSAND OF BLACKDOWN. THE UPPER GREENSAND OF KENT; ISLE OF WIGHT; CAMBRIDGE. THE SO-CALLED COPROLITE BEDS. ORGANIC REMAINS OF THE UPPER GREENSAND. FOREIGN EQUIVALENTS OF THE GAULT. BELGIUM; MEULE DE BRACQUEGNIES. FRANCE; SWITZERLAND; GERMANY.

Another break in the stratigraphical sequence of minor, though not inconsiderable, importance separates the Upper from the Lower Cretaceous or Neocomian series. At the close of the latter period, a wide-spread and long-continued movement of subsidence deepened the existing seas and submerged the contiguous land, changing the drainage areas and originating a new and special class of sediments. In England we have no marked chain of hills as the resultant of this disturbance, but its effects are shown in the circumstance that the several Oolitic formations were further tilted at various small angles and more or less denuded, and that over the strata so disturbed the Gault and Upper Greensand seas gradually and transgressively encroached as the subsidence slowly proceeded.

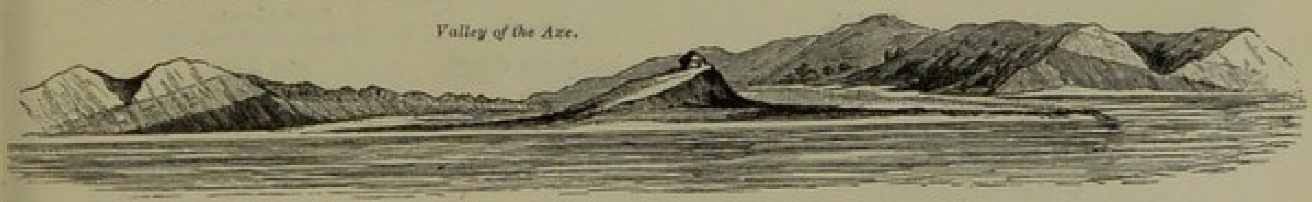

FIG. 143. *View of the Cliffs on the Dorset coast near Axmouth.* (Buckland.)
The upper light part represents the Chalk; the dotted part the Upper Greensand and Gault, the dark lower part the New Red Sandstone. This section shows also a slight anticlinal line in the direction of the valley.

Further Submergence. While in Kent and Sussex the Chalk, Gault, and Upper Greensand succeed in due order and conformably to the Lower Greensand, the former pass, as they range westward, from off the Neocomian strata, and spread over the several Jurassic formations, resting finally on the Triassic strata of Devonshire. Again, whereas the Gault at Nuneham, near Oxford, lies on a considerable thickness of Lower Greensand, at Culham, near Abingdon, it reposes on the Kimmeridge Clay. A still more important physiographical change is indicated by the fact that the Gault, in its range from Kent into Essex and Hertfordshire, passes altogether off the Mesozoic strata directly on to Palæozoic rocks. This happened in consequence of the submergence of an old Continental land that existed during the Triassic and Jurassic periods, north and eastward of the Thames area.

The advance of the sea over these old lands is marked by pebble and conglomerate beds derived from the local rock débris. Thus we have at the base of the Gault (as we had at the base of the Neocomian) detrital beds derived, in Kent from the underlying Lower Greensand, and under London from the contiguous Palæozoic rocks[1]. These indications of change and erosion are not confined to the one stage, but are repeated at intervals in the Gault, and through the overlying sands and the Chalk, and that in a way which would indicate the changes of level to have been prolonged, but with intervals of rest. In consequence of these frequent changes the sedimentation of the early Cretaceous seas was very varied and irregular—argillaceous deposits prevailing at one time or in one place, arenaceous deposits at others, and both being more or less calcareous and mixed throughout with variable proportions of *glauconite*. As time passed, the mechanical element (the sands and clays) gradually became less, while the organic and chemical elements, productive of the calcareous matter, as steadily increased, until at last, for long ages, the sediments in the Cretaceous sea consisted of little but decaying organic débris, and of a carbonate-of-lime precipitate, by means of which the successive divisions of the Chalk were built up.

Leaving for future consideration the minor subdivisions and the palæontological zones, the broad divisions of the Upper-Cretaceous series in England and France are, as under, in descending order:—

English.	French.	Approximate mean thickness.
White Chalk with flints	Senonian Stage	400 feet.
White Chalk without flints	Turonian ,, ...	150 ,,
Chalk-marl (part)	Cenomanian ,, ...	300 ,,
Chloritic Chalk		
Upper Greensand		
Gault	Albian ,, ...	150 ,,

[1] If a line be drawn from the north of London to the neighbourhood of Calais, and thence to Douai and Mezières, it will be found that, whereas to the south of that line the Chalk and the Gault rest on the Lower Greensand and Jurassic strata, to the north of the line the Lower Greensand and the Oolites are wanting, and the Chalk and Gault rest directly on Palæozoic rocks.

THE GAULT.

'Gault' is a provincial English name applied by geologists to a group of marls and dark blueish-grey clays, 100 to 200 feet thick, lying beneath the Chalk and Upper Greensand. They are very calcareous and contain some concretionary layers, with a few sandy beds and occasional seams of phosphatic nodules. These are thin and unimportant, with the exception of two seams from one to three feet thick, the one at the base of the lower division of the Gault, and the other at the base of the upper division. The commercial value of these phosphates has led to the opening of many pits as well in the English as in the French area, which, with the numerous brick-pits, afford great facilities for obtaining Gault fossils. The best locality, however, for collecting them is Eastware Bay, on the coast about one mile east of Folkestone. The several beds there come to the surface in succession, and the fossils are abundant; while, owing to the constant washing of the clay by the sea, a fresh crop is always available.

Mr. F. G. H. Price, F.G.S.[1], divides the Folkestone Gault into an upper and a lower series, separated by a junction-bed, the whole forming eleven zones, characterised by particular species of Ammonites and other fossils.

Upper Gault. Pale grey marls and marly clays, with one greensand seam, 3 ft. thick, and a layer of phosphatic nodules; 70 feet 8 inches.	11. Zone of Ammonites rostratus, Sby. (A. inflatus, D'Orb.), Pl. X, fig. 5. 10. Zone of Kingena lima. 9. " Ammonites varicosus.
Junction-Bed. Dark clays with two layers of phosphatic nodules and remanié fossils; 7 feet.	8. " Am. cristatus. 7. " Am. auritus.
Lower Gault. Light coloured passing down into dark stiff clay, with several lines of phosphatic and one of pyritic nodules at base; 21 feet 8 inches.	6. " Am. denarius. 5. " Am. lautus. 4. " Am. Delaruei. 3. " Crustacea. 2. " Am. auritus, var. 1. " Am. interruptus, Pl. X, fig. 4.
Total, 99 feet 4 inches.	

Owing to the soft, easily weathered character of the beds, the Gault forms a line of depression everywhere at the foot of the Chalk escarpment.

Range and Thickness. In Kent the thickness of the Gault is estimated at an average of about 150 feet[2]. Under London it is from 130 to 160 feet thick, and rests on Devonian rocks. At its outcrop in Bedfordshire it attains a thickness of above 200 feet, and then thins out as it ranges through Cambridgeshire. Mr. Beete Jukes considered this diminution of volume to be due not so much to the thinning out of the Gault as to the removal of the upper beds by denudation.

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[1] 'Quart. Journ. Geol. Soc.,' vol. xxx. p. 342; and 'The Gault,' 1879.

[2] The thickness of the Gault under Shoreham, near Sevenoaks, was found to be 226 ft., but in a recent boring at Heaversham, 3½ miles south-east of Shoreham, it was traversed for about 300 ft. without reaching its base.

The Gault is largely developed in Buckinghamshire, but is reduced to eighty feet in Wiltshire. As it ranges through Oxfordshire an interesting section is exposed in a brick-pit at Culham, near Abingdon, the Gault being there brought into direct superposition on the Kimmeridge Clay, or only separated from it by an occasional foot of ferruginous grit in consequence of the denudation of the Lower Greensand and Portland beds. The two clays are so much alike that, were it not for their organic remains, they could not be distinguished. The fossils, however, are very distinctive; the upper beds containing such characteristic Gault fossils as *Inoceramus concentricus*, *Nucula pectinata*, *Ammonites lautus*, *Belemnites minimus*, and others; and the lower the common Kimmeridge fossils, *Cardium striatulum*, *Ammonites biplex*, *Thracia depressa*, etc.

Elsewhere the Gault alters its character, and is known under other names. With this change in composition, there is a change in its organic remains, which will be noticed further on.

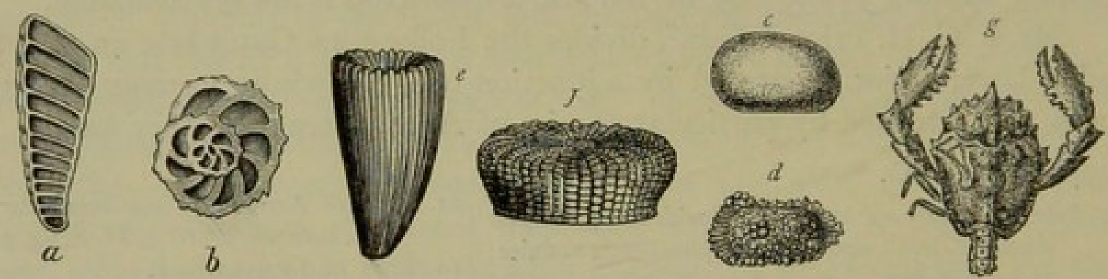

FIG. 144. Rhizopods, Corals, and Crustacea of the Gault.
a. Vaginulina truncata, Reuss, × 25. *b. Pulvinulina spinulifera* (Reuss) × 25. *c. Cytherella ovata* (Roemer), $\frac{10}{1}$. *d. Cythereis ornatissima* (Reuss), $\frac{15}{1}$. *e. Cyclothyathus Fittoni*. *f. Trochocyathus conulus*, nat. size. *g. Palæocorystes Stokesii.*

Organic Remains. The molluscan fossils of the typical Gault of the south of England amount to 258 species, of which 64 pass up from the Lower Greensand.

The following are some of the more common species :—

Protozoa. Some beds of the Gault abound in *Foraminifera*, amongst which the most common are species of Nodosaria, Dentalina, Vaginulina, Cristellaria, Bulimina, and Pulvinulina.

Few *Corals* are found; the most characteristic are *Cyclocyathus Fittoni* and *Trochocyathus Harveyanus*, with species of *Podoseris* and *Smilotrochus*.

Echinoderms are rare; a Crinoid, *Pentacrinus Fittoni*, and a Star-fish, *Hemiaster asterias*, are the most common.

Annelids. Serpula corticulata and *S. plexus* are common in the Upper Gault.

Crustacea are represented by *Palæocorystes Stokesii* and *Etyus Martini*. Bivalved *Entomostraca*,—*Cythereis*, *Cytherella*, and *Bairdia*—are numerous in some of the beds.

Of *Brachiopods*, the characteristic species are *Terebratula biplicata*, and *Kingena lima*.

Some *Monomyarian Bivalves* are very characteristic, such as *Inoceramus concentricus*, *I. sulcatus*, *Plicatula pectinoides*, and *Pecten orbicularis*.

Of *Dimyarian Bivalves*, the *Nucula bivirgata*, *N. pectinata*, and *Cardita tenuicosta* are common, as are some *Univalve Mollusca*,—*Solarium conoideum*, *Rostellaria carinata*, *Scalaria gaultina*, and *Dentalium decussatum*.

Cephalopods are abundant: *Ammonites interruptus*, *A. denarius*, *A. splendens*, *A. lautus*, *A. varicosus*, *Hamites intermedius*, and *H. rotundus*, with *Belemnites minimus* and *B. ultimus*, are amongst the most common. Of these fossils, by far the most characteristic are the Ammonites, of which there are thirty-five species, eight being peculiar to the Gault. As with the Lias, the Ammonites define particular zones.

Fishes are few in number; they include *Otodus subinflatus* and *Saurocephalus lanciformis*.

Of *Reptiles*,—*Ichthyosaurus campylodon* and *Polyptychodon interruptus* may be noticed.

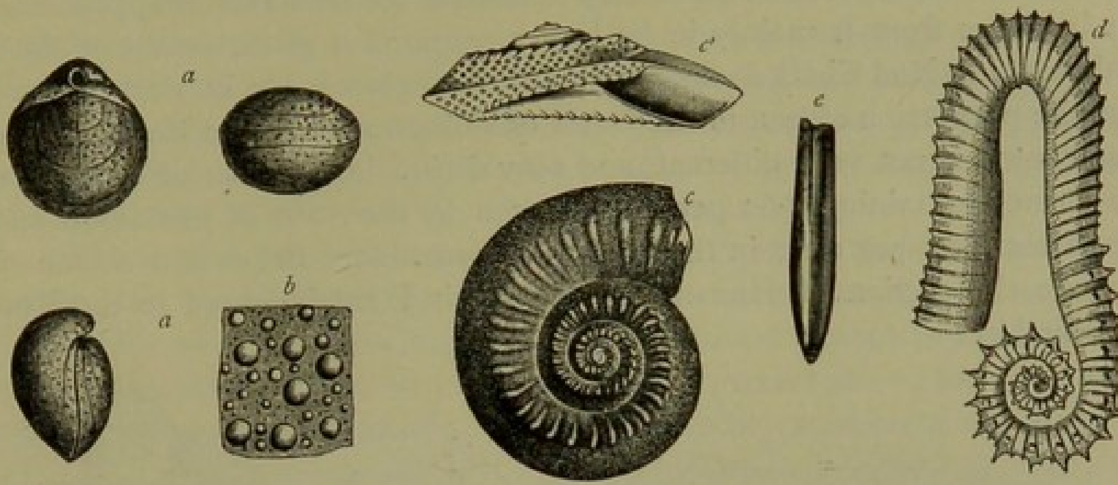

FIG. 145. Other Fossils of the Gault.
a. Kingena lima, Defr.; *b. Surface magnified*, Mant. *c., c'. Solarium ornatum*, Sby. *d. Ancyloceras spinigerum*, Sby. *e. Belemnites minimus*, List.

Variability of Conditions. Notwithstanding, however, the comparatively homogeneous character of the Gault at Folkestone, there is a palæontological break between its lower and its upper beds, almost as important as that between the Lower Greensand and the Gault. Mr. Price found that in the Folkestone Gault, out of a total of 292 fossils, the two divisions have only sixty-five species in common, and that as many as fifty-seven new species make their appearance in the upper division. *Ammonites varicosus*, *A. inflatus*, *Kingena lima*, *Inoceramus sulcatus*, *Avicula Rauliniana*, *Scaphites æqualis*, etc., first occur here.

Bed No. 8 contains as many as twenty species peculiar to it. It is a junction bed, which Mr. Price includes in the Lower Gault.

In the Isle of Wight the Gault consists of about 100 feet of dark sandy clays with very few fossils. It is reduced to 30 feet in the Isle of Purbeck; and becomes gradually thinner, and passes into, or is replaced by, sands as it ranges further westward. The lower division of the Gault at Lyme Regis consists of a dark-grey clay, difficult to distinguish from the Lias on which it rests. Over this is a few feet of sand, with siliceous concretions ('Cowstones'). The clay bed has been referred to the Lower Gault of Folkestone, and the sand and Cowstones to the Upper division of the Gault probably. These are succeeded by 80 to 90 feet of quartzose sands, with *Exogyra conica*, *Pecten asper*, and other fossils which have been assigned by some geologists to the Upper Gault, and by others to the Upper Greensand, or to the Warminster beds[1].

[1] De Rance, 'Geol. Mag.' for June 1874; and C. J. A. Meyer, 'Quart. Journ. Geol. Soc.,' vol. xxxi. p. 369.

The Red Chalk of Hunstanton and Yorkshire. As the Gault ranges northwards from Cambridgeshire into Norfolk the argillaceous beds gradually disappear, and are replaced by a hard marly red chalk with quartz grit and small pebbles. This is very dissimilar to the Gault in appearance, but it differs from it mainly in its larger proportion of carbonate of lime. Although the Red Chalk looks much more ferruginous, Mr. D. Forbes found that the proportion of iron in the Gault of Folkestone and the Red Chalk of Hunstanton is not very different, and only differs in its state of oxidation, the former containing 4·62 per cent. of iron in the state of protoxide, and the latter 4·10 per cent. in the state of sesquioxide. Below is a sketch of the fine cliff-section at Hunstanton, for which I am indebted to the Rev. T. Wiltshire.

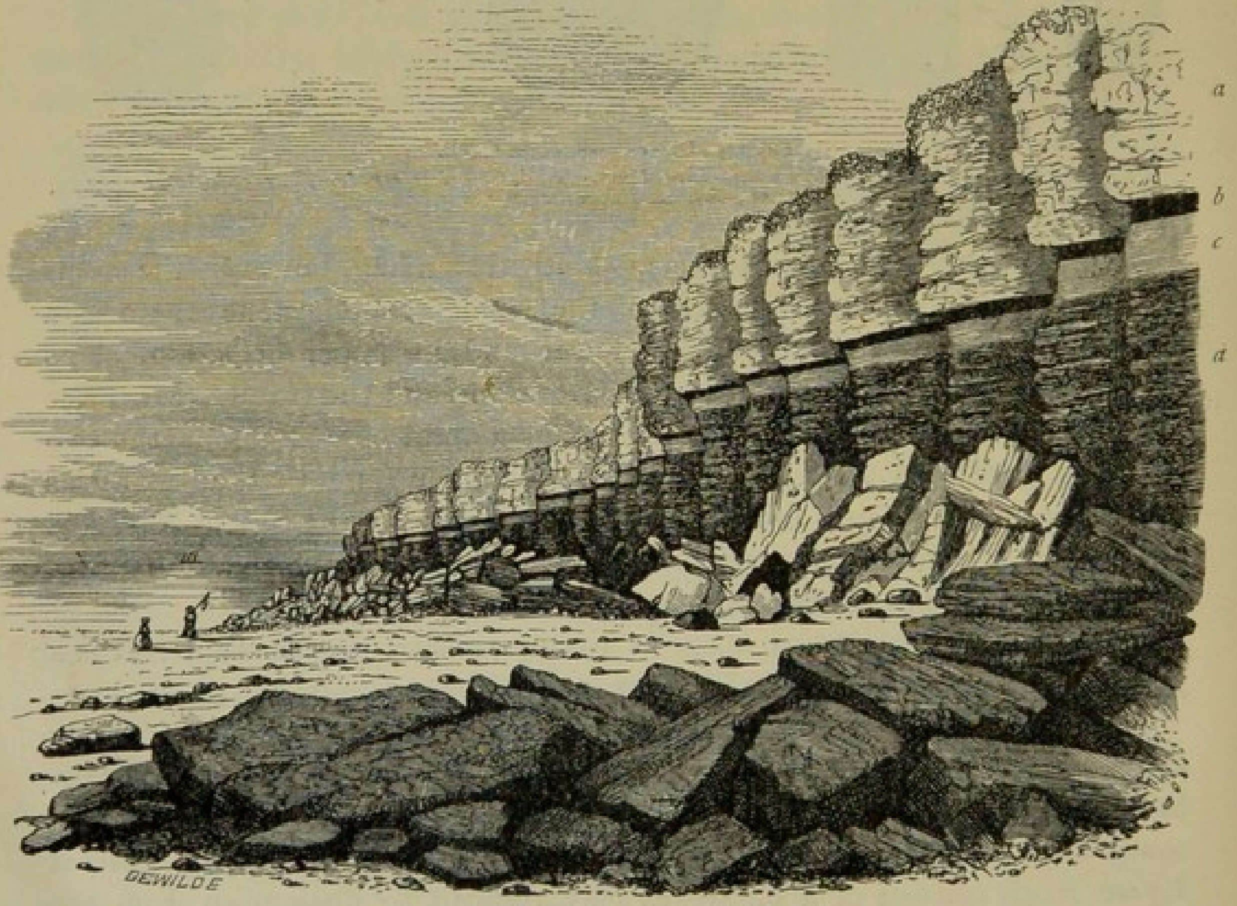

FIG. 146. View of Hunstanton Cliff, Norfolk.
a. Hard White Chalk, 40 ft. *b. Red Chalk*, 4 ft. *c. Soft yellow Sandstone*, 10 ft. *d. Ochreous pebbly Sandstone* (*Carstone*), 60 ft.

Professor Wiltshire[1] gives a list of sixty species of fossils from these beds, and considers that, as a whole, they represent the Upper Gault of Folkestone. The differences may be due to distance and to difference of conditions. Amongst the common fossils found at Hunstanton are *Podoseris mamilliformis*, *Terebratula biplicata*, *Belemnites minimus*, *Ostrea Normaniana*, *Spondylus striatus*, *Ammonites auritus*, and *Am. lautus*.

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[1] 'Quart. Journ. Geol. Soc.,' vol. xxv. p. 185.

In Lincolnshire the Red Chalk is from 10 to 12 feet thick; and in Yorkshire it passes into a red marl or clay, 30 feet thick, resting unconformably on Neocomian and Oolitic strata down to the Inferior Oolite[1].

The Greensand of Blackdown. The exact correlation of these beds is still uncertain. By some geologists they are referred to the upper division (Folkestone beds) of the Lower Greensand, and by others either to the Gault or to the Upper Greensand. Mr. Meÿer is of opinion that they underlie the true Upper Greensand, and may be synchronous in part with the Gault, and in part with the Upper Neocomian.

These sands are about 100 feet thick, are light-coloured and quartzose, and contain layers of chert and of siliceous sandstones, which have been long worked for whetstones for scythes. The shells are commonly replaced by chalcedonic infiltrations, and are admirably preserved. The number of species amounts to about 160, amongst the most common of which are:—

Pecten orbicularis, *Sby.*
Cardium Hillanum, *Sby.*
Cyprina cuneata, *Sby.*
Thetis major, *Sby.*
Cucullæa carinata, *Sby.*
Ammonites crenatus, *Brug.*
Nautilus elegans, *Sby.*
Aporrhais Parkinsoni, *Sby.*
Arca glabra, *Park.*
Trigonia alæformis, *Park.*

THE UPPER GREENSAND[2].

This deposit consists of light-coloured quartzose sands and soft sandstones, more or less calcareous, and more or less glauconiferous. In East Kent it is only about 15 feet thick. In the neighbourhood of Godstone and Merstham it is 25 to 30 feet thick, and forms a soft sandstone, which is worked for hearthstones and ovens, and for slabs used in polishing plate-glass. At Eastbourne it is 26 feet thick, and forms a soft, pale-green, calcareous sandstone. It is thicker in the western parts of the Weald.

In the Isle of Wight the Upper Greensand attains a thickness of about 150 feet, and contains many fossils. It is about 100 feet thick in Berkshire (Didcot), where it is divisible into an upper mass of light sands, with a subordinate bed of very dark-green sand, and a lower division of hard sandstones with cherty beds, in parts of which fossils are not uncommon. It expands to a thickness of 150 feet or more in the neighbourhood of Devizes, where it contains in places layers of large nodular cherty concretions and numerous fossils.

The so-called Upper Greensand of Warminster may possibly, as suggested by Professor E. Renevier and Mr. Meÿer, belong to the base of the next division above this, forming the base of the Chalk series.

[1] Judd, 'Quart. Journ. Geol. Soc.,' vol. xxiv. p. 227, and vol. xxvi. p. 330.

[2] The name 'Greensand' originated from the circumstance that some intensely green beds above the Gault in the Isle of Wight were first the subject of observation. The term was then extended to the equivalent beds, lighter in colour, of Kent, and afterwards, in consequence of a general similarity of fossils and occasionally of colour, the term Lower Greensand was given to strata below the Gault.

Phosphatic nodules are only occasionally present in the Upper Greensand, but at the base of the Chalk-marl in Cambridgeshire there is a thin layer of small dark-coloured or black nodules, containing 60 per cent. of phosphates, which is largely worked as a mineral manure. Professor Bonney[1] and Mr. Jukes-Brown [2] have shown by the enclosed fossils that these nodules are largely or wholly derived from the denudation of the Upper Gault; and that this thin detrital zone is probably the representative of the Upper Greensand. It has also been suggested that these beds, like those of Warminster, may belong to the next succeeding zone, or to that of the Glauconiferous Chalk of the Isle of Wight.

In the extensive coprolite-diggings of Cambridgeshire a large number of fossils have been obtained, of which as many as 210 species are, according to Mr. Jukes-Brown, derived from the Gault, and seventy-three are proper to the bed itself. Amongst them are, *Belemnites ultimus*, *Inoceramus sulcatus*, *Plicatula inflata*, *Terebratula biplicata*, *Ostrea vesiculosa*, and other well-known Upper-Gault and Greensand fossils.

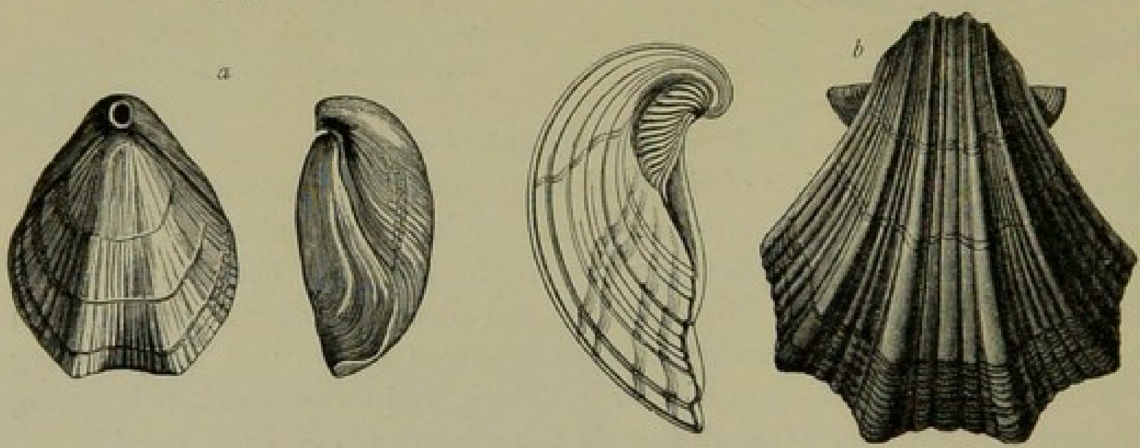


FIG. 147. Fossils of the Upper Greensand.
a. Terebratula biplicata. *b. Pecten quinquecostatus*, Sby. (*Janira atava*, Lam.).

Organic Remains. As a whole, the Upper Greensand is not very fossiliferous, and the organic remains are of a very local occurrence. They are scarce in Kent and Sussex, more abundant in Berkshire, but in Wiltshire, where this deposit attains its greatest importance, it is rich in organic remains. Mr. W. Cunnington obtained from it, in the neighbourhood of Devizes, a collection of nearly 200 species, now in the British Museum.

Amongst the common fossils of the Upper Greensand are:—

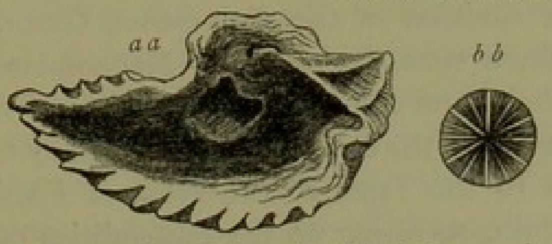
Terebratula biplicata, *Sby.*
Terebrirostra lyra, *Sby.*
Exogyra conica, *Sby.*
Ostrea frons, *Park.*
Pecten quinquecostatus, *Sby.*
P. asper, *Lam.*
Rostellaria carinata, *Mant.*
Ammonites inflatus, *Sby.*
A. Renauxianus, *D'Orb.*
Hamites armatus, *D'Orb.*
Belemnites ultimus, *D'Orb.*
Stellaster Comptoni.

The Upper Greensand is very rich in Sponges. The Lithistid Sponges

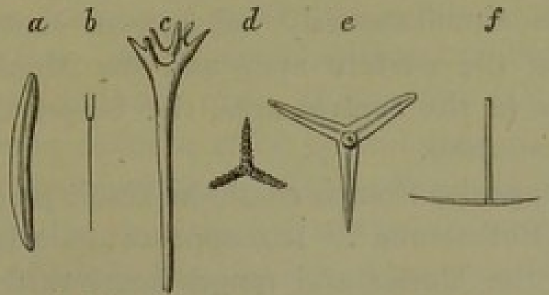
[1] 'Quart. Journ. Geol. Soc.,' vol. xxxi. p. 256. [2] 'Proc. Geol. Assoc.,' vol. iii. p. 1.

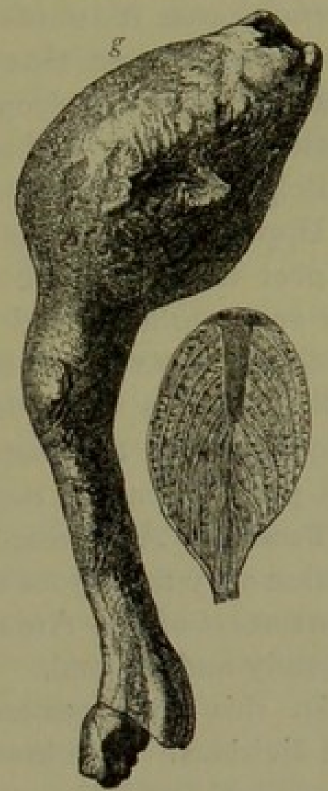
especially are extremely abundant. Siphonia abounds at Warminster, and the structure is often apparent in prepared sections. In some localities the beds are largely made up of spicula, many of which resemble those of the Lower Greensand. Calcisponges are also numerous in some localities.

FIG. 148. Upper-Greensand Fossils.



a a. Ostrea frons, Park. *b b. Microbasia coronula.*





Spicula (*a–f*) and Sponge (*g*). (After Hinde.)
a. Reniera truncata. b. Sestrostomella rugosa. c. Geodites Haldonensis, Carter. *d. Pachastrella* (*Minolites*) *quadriradiata*, Carter. *e. Pachastrella* (*Dercitus*) *Haldonensis*, Carter. *f. Tremacystia D'Orbignyi. g. Siphonia tulipa*, Zittel.

Foreign Equivalents. Belgium. There is no true Gault in Belgium, but MM. Briart and Cornet have shown that the 'Meule de Bracquegnies' of Hainaut contains a series of fossils closely related to those of the Greensand of Blackdown[1]. Out of a total of ninety-three species described by them, forty-two are Blackdown forms. Amongst the most common are,—*Cardium Hillanum*, *Ostrea conica*, *Cyprina angulata*, *Trigonia dædalæa*, *T. Elisæ*, *Thetis major*, *Turritella granulata*, *Aporrhais Parkinsoni*, etc. The *Trigonia Elisæ* of Bracquegnies is a very abundant and characteristic species which seems to replace the *T. alæformis* of Blackdown. There is almost an entire absence of Brachiopods and Cephalopods.

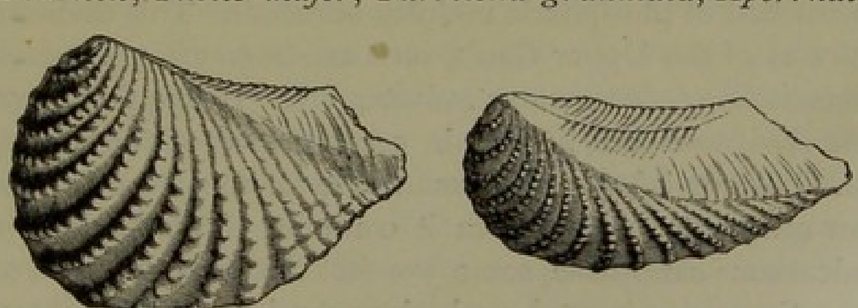


FIG. 149. *Trigonia Elisæ*, Cornet and Briart.

The Meule consists of beds of green sand, soft porous sandstone, and

[1] 'Mém. Acad. Roy. de Belgique,' vol. xxxiv.

hard siliceous concretions, and, like the *Gaize* of Argonne, contains a large proportion of soluble silica, while the fossils, as with those of Blackdown, are commonly in the state of siliceous casts. At the base of the Formation is a conglomerate bed of old-rock pebbles. Although only of limited superficial area, it attains at Harchies a thickness of about 600 feet.

It would seem that the lower division of the Folkestone Gault, deposited in not very deep but confined seas, spread over Neocomian and Jurassic strata only, and scarcely touched on the Palæozoic strata of France and Belgium. A further subsidence led to the extension of the Upper Gault and Upper Greensand as far as on to the Trias of the West of England, and over the Palæozoic rocks of Hainaut, filling up the inequalities of the older rock surfaces, and increasing the depth of the central sea. Very probably it was over these lands simultaneously submerged, that the Blackdown beds were deposited in the western area, and the Meule de Bracquegnies in the eastern; while in the central area, the Upper Gault and Upper Greensand succeed in due order.

France. At Wissant, on the opposite French coast, the Gault presents a section very analogous to that at Folkestone[1]. It reappears again in the Departments of the Ardennes and the Meuse, and ranges southward into Burgundy and beyond.

In this north-eastern part of France, the Gault or Albian forms three divisions. The lower part consists of clayey green sands with a bed of phosphatic nodules, and is characterised by the presence of *Ammonites mamillaris*, *Natica gaultina*, etc. This division, which is about thirty feet thick, would seem to correspond with the upper part of the Folkestone sands,—above this is a stiff dark clay, varying from twenty to a hundred feet in thickness, and containing *Ammonites interruptus*, *A. lautus*, *Hamites rotundus*, *Nucula pectinata*, and other fossils of the Lower Gault; while a variable set of glauconiferous clays, sands, and soft sandstones, with a basement bed of phosphatic nodules, succeeds. This division is characterised by species of the Upper Gault, such as *Ammonites rostratus*, *A. inflatus*, *Pecten Raulinianus*, *Inoceramus sulcatus*, etc. It acquires a great development in the Ardennes and Meuse, in consequence of the setting-in of a local bed (la Gaize de l'Argonne), remarkable for the large proportion—fifty to sixty per cent.—of soluble silica it contains. This *Gaize* is a light, soft, porous calcareous sandstone, some 300 feet thick, and forms a soil of great fertility.

Some continental geologists consider that all these three divisions belong to the Albian stage (Gault); but, at the same time, place them in the Lower Cretaceous series. Others place them at the base of the Upper Cretaceous; whilst M. Barrois would restrict the Albian to the two lower

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[1] Topley's 'Lower Cretaceous Beds of the Bas Boulonnais,' Quart. Journ. Geol. Soc., vol. xxiv. p. 472; see also C. Barrois on the 'Folkestone Beds,' Ann. Soc. Géol. du Nord, vol. iii. p. 23; and 'Le Gault dans le Bassin de Paris,' Bull. Soc. Géol. de France, 3me sér., vol. iii. p. 707.

divisions, and place the upper division at the base of the Cenomanian stage of the Chalk. Professor Gosselet remarks of the Albian of the North of France, as we have had occasion to mention with reference to the English Gault, that the several beds of pebbles and phosphatic nodules prove the many changes of level and the frequent erosion which the sea-bed underwent during this period[1],—changes which, while they destroyed certain species in one area, allowed them to survive in others. It is this which tends considerably to complicate the exact synchronism of the different palæontological zones of this portion of the Cretaceous series.

In the South of France the Gault is represented by 30 to 50 feet of green sandstones and siliceous limestones with *Ammonites inflatus*, *Belemnites minimus*, etc.; while in the Pyrenean district it consists of shales, marls, and sandstones, attaining, in places, a thickness of from 300 to 1500 feet. In the neighbourhood of Foix it consists of a dark grey fossiliferous schistose rock. *Belemnites minimus* and *Ammonites inflatus* still, however, continue to be typical forms.

Switzerland. At the Perte-du-Rhône the yellow marlstones of the Aptian are overlain by pale green sands and reddish sandstones of Albian age, which in the Eastern Alps pass into thick grey compact limestones. The strata are often rich in fossils, amongst which are *Ammonites inflatus*, *A. mamillaris*, *Hamites intermedius*, *Inoceramus sulcatus*, etc.

The Gault in Switzerland, as in France, has been divided into three groups, the upper one of which is sufficiently distinct to lead M. Renevier to separate it from the other two under the designation of the Vraconnian beds, or it may correspond with our Upper Greensand. He considers also that the Gault of Switzerland has few palæontological relations with the Aptian (Lower Greensand), whereas it is closely related to the Cenomanian, and forms part of the group for which he proposes the term of Mesocretaceous[2].

Germany. The Gault does not extend to Southern Germany, but occurs in Northern Germany, where it consists of light-coloured marls with subordinate limestones, and of grey clays, often glauconiferous; the upper zone (or Flammenmergel) is characterised by *Avicula gryphæoides*, and the lower by *Belemnites minimus*. Credner unites these divisions with the underlying divisions, containing *Ammonites Milletianus*, *Ancyloceras Mathesonianum*, and other Aptian or Upper-Neocomian species, and including the well-known Caprotina-beds; thus making the Aptian subordinate to the Albian, and embracing both series in a 'Gault' or Albian group[3].

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[1] The student should consult the interesting maps given by Professor Gosselet in the second part of his 'Esquisse Géologique du Nord de la France, etc.,' 1881.

[2] 'Bull. Soc. Vaud. Sci. Nat.,' vol. ix., Nos. 55 and 58, and 'Bull. Soc. Géol. de France,' 3me sér., vol. iii. p. 704.

[3] 'Traité de Géologie,' Fr. ed. 1879, pp. 550 and 555.

CHAPTER XIX.

THE UPPER CRETACEOUS STRATA (*continued*): THE CHALK.

STRATIGRAPHICAL DIVISIONS OF THE CHALK. EAST KENT. THICKNESS OF THE CHALK. CHALK OF SCOTLAND: IRELAND: SOUTH OF ENGLAND. PETROLOGICAL CHARACTERS OF THE CHLORITIC MARL; CHALK-MARL; LOWER CHALK WITHOUT FLINTS; CHALK-ROCK; CHALK WITH FLINTS; UPPER CHALK. ORGANIC REMAINS. SPONGES; CORALS; MOLLUSCA, ETC. PALÆONTOLOGICAL ZONES. KENT. ISLE OF WIGHT. SURREY. CAMBRIDGESHIRE; YORKSHIRE. FOREIGN PEBBLES. WATER-BEARING CAPACITY. CONTINENTAL EQUIVALENTS OF THE UPPER CRETACEOUS SERIES. DIVISION INTO GEOGRAPHICAL ZONES. THE REGION OF WHITE CHALK: NORTH OF FRANCE: BELGIUM: HANOVER: DENMARK: POLAND: RUSSIA. REGION OF SANDSTONES: SAXONY AND BOHEMIA. REGION OF LIMESTONES: SOUTH OF FRANCE: THE PYRENEES: SPAIN: PORTUGAL: THE JURA: AUSTRIA: THE MEDITERRANEAN AREA. THE CRETACEOUS ROCKS OF INDIA: SOUTH AFRICA: AUSTRALIA: NEW ZEALAND: AMERICA. PASSAGE-BEDS: CANADA.

THE subjects of this and the following chapter are of exceptional interest. The lithological character of the White Chalk with its accompanying flints is so different, on the whole, from that of the rocks of any other formation, that their mode of deposition and origin gives rise to an unusual number of questions for discussion and speculation. Many geologists have contended for an entirely organic origin of the Chalk; others have attributed an analogous origin to the flints; the chemical side of the questions is of equal importance, but has scarcely had the same attention. I have therefore dwelt somewhat fully on these several subjects—not indeed at the length they would require, but probably sufficiently so to show their many phases, and to suggest some other views for consideration.

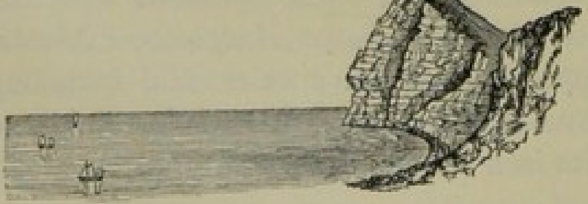

FIG. 150. *View of Shakespeare's Cliff, Dover.*

Divisions of the Chalk. The original description of the Chalk Cliffs of Dover by William Phillips[1] still serves, with the addition of Whitaker's account of the

[1] 'Trans. Geol. Soc.,' 1st ser., vol. v., 1821.

Chalk of the Isle of Thanet and the coast of Kent[1], as the stratigraphical type for the Chalk in the South of England, where it forms the great centre to which all the other members of the Upper-Cretaceous series are subordinate. The Chalk of Sussex was first described by Mantell[2], and afterwards by Dixon[3]. In the Isle of Wight it has been described by E. Forbes and Ibbetson[4], as well as by Dr. Barrois, in the London Basin and Isle of Thanet by Whitaker[5], and in Yorkshire by Phillips[6] and others. In East Kent the stratigraphical divisions are as under, in descending order:

Chalk with Flints.	1. Margate Chalk, with few flints ...	80 feet.
	2. Broadstairs and St. Margaret's Chalk, with many flints and few organic remains ...	350 " (2 and 3)
	3. Dover Chalk, with many flints and many organic remains ...	
	4. Chalk, with few flints, centre of Shakespeare's Cliff ...	130 "
Chalk without Flints.	5. Nodular Chalk, without flints, and with many organic remains; projecting part of Shakespeare's Cliff ...	90 "
	6. Chalk, without flints, and with few fossils; base of Shakespeare's Cliff ...	50 "
Chalk-Marl.	7. Grey Chalk at the base of the cliffs west of Shakespeare's Cliff	200 "
	8. Chalk with green grains ...	10? "
		910 feet.

Under London (Kentish Town), where the upper divisions are wanting, the Chalk is 645 feet thick. At Norwich a well-boring has proved a thickness of 1152 feet. There are beds in the Norfolk Chalk which belong to a higher zone than the Chalk of Kent and Sussex. They contain scarce remains of Mosasaurus and Leiodon; and they are further characterised by the abundance and variety of their Sponges, and by large massive Paramoudras. In Yorkshire the Chalk is about 700 feet thick, and is also noted for the number and beauty of its Sponges.

In Scotland, the former existence of Cretaceous strata had been inferred from the occurrence of loose flints on the surface of the ground in parts of Banffshire. More recently, not only have strata of Lower-Cretaceous age been found on the West Coast, but fragments of White Chalk, with great quantities of angular flints, were found associated with volcanic débris by Prof. Judd, and since then a White Chalk with flints, similar to that of Antrim, and with Belemnitellæ, has been discovered *in situ* in the Isle of Mull[7].

The White Chalk-with-flints in the north of Ireland, where it is overlain by masses of dark basalt, constitutes a striking feature of the cliffs

[1] 'Quart. Journ. Geol. Soc.,' vol. xxi. pp. 295, 404, and xxvii. p. 93.
[2] 'Geology of the South Downs,' 1822.
[3] 'Geology of Sussex,' 2nd edit. Edited by Prof. Rupert Jones, 1878.
[4] 'Quart. Journ. Geol. Soc.,' vol. i. p. 190.
[5] 'Mem. Geol. Survey,' vol. iv. p. 14 et seq.
[6] 'Geology of Yorkshire,' edit. by Etheridge.
[7] 'Quart. Journ. Geol. Soc.,' vol. xxxiv. p. 228.

between Belfast and the Giant's Causeway. Instead, however, of presenting the soft earthy character of the Chalk of the South of England, it has been hardened by the basalt into a white limestone, as compact and dense as the palæozoic limestones. The flints also are baked and some are coloured red, owing to the oxidisation of the iron. Huge Paramoudras, like those of Norfolk, are not uncommon. The lower divisions of the Chalk assume in Ireland a similar arenaceous character to that which the Warminster and Upper Greensand beds have in England, but they are of less dimensions.

The Chalk has a very uniform petrological character over considerable areas in England, the North of France, and Belgium, so that the following description of its several divisions applies generally to the South of England, and in great part to the North of France.

Chloritic Marl. This constitutes a bed from 2 to 15 feet thick at the base of the Chalk. It generally forms a solid and compact rock of a light-yellow colour, in which are interspersed grains of glauconite, and, in places, of quartzose grit. Sometimes it passes into a greenish marl or into green sand. It occasionally has a basement-layer of dark-coloured phosphatic nodules, derived by denudation from the underlying strata. These so-called 'coprolites' are largely worked in many places. It is to this zone that the Cambridgeshire bed is generally referred. Mr. Meÿer considers that the Greensand of Warminster is also of this age.

Chalk-Marl. This division consists of beds of soft, light-grey marl, with others which are compact and hard. The lower beds are sometimes glauconiferous. It contains no flints, but nodules of iron-pyrites are common. Some of the beds are sandy, and some others, as well as the underlying Chloritic Marl, are remarkable for the quantity of soluble silica which they contain. *Ammonites varians* and *A. Mantelli* are common in this and the preceding stage, but the more characteristic fossils of this zone are *Am. Rothomagensis*, *Turrilites tuberculatus*, and *T. costatus*.

Lower Chalk, without Flints. This Chalk is of a dull white, with a tinge of yellow passing up into pure white. It is composed of a series of beds, each from two to three feet thick, generally soft, though occasionally hard and nodular. Nodules of iron-pyrites are common, but not so common as in the underlying Chalk-marl. The sandy chalk quarried as a building stone at Totternhoe belongs either to the base of this division or to the top of the Chalk-marl. Among the common fossils of the Chalk-without-flints are *Ammonites peramplus*, *Terebratula gracilis*, *Rhynchonella Cuvieri*, *Echinoconus subrotundus*, and *E. globulus*.

Chalk-Rock. This is a thin band, not exceeding 2 to 12 feet in thickness, which Mr. Whitaker has shown to form in the South of England a zone of remarkable persistence between the Lower Chalk (without flints) and the Upper Chalk (with flints). It consists, in some places, of irregular nodular masses of a very hard light-yellow limestone, often coated with a thin film of green earth, and imbedded in a white limestone matrix. The nodules generally contain a small proportion of phosphate of lime. This circumstance, combined with its hardness, readily distinguishes this 'Chalk-rock' from the beds above and below. It is often so hard as to be quarried for road-metal. This rock is well developed and quarried on the slope of the hills above Hendred and Wantage. It is remarkable for the number of its Gasteropods, chiefly casts of *Solarium* and *Pleurotomaria*; it also contains *Terebratulæ*, *Scaphites*, and *Baculites*.

Chalk-with-Flints. This constitutes the great mass of our Chalk hills. It consists of homogeneous beds, generally from one to four feet in thickness, of a pure white, soft, and earthy calcareous rock, divided by layers of nodular black flints, consisting of subtranslucent amorphous silica, tinged black by the presence generally of a small quantity of carbon. Sometimes these flints run into thin tabular masses. Besides the irregular layers of nodular flints, the Chalk is often traversed at various angles by oblique sheets of tabular flint; a few flints occur irregularly dispersed in the beds.

This division of the Chalk is composed of an almost pure carbonate of lime, the foreign ingredients rarely exceeding two to three per cent. of the mass. It is often rich in visible organic remains. If further this Chalk be rubbed down with a fine brush under water, it is found to consist of a matrix of impalpable carbonate of lime, full of microscopic organisms so minute that upwards of a million are sometimes contained in a cubic inch of Chalk. These organisms are chiefly the shells of small Foraminifera, a few tests of Polycystina, spicules of Sponges, innumerable fragments of Polyzoa and Molluscan shells (*Inoceramus* in particular). Together with these are numbers of extremely minute calcareous oval discs termed Coccoliths, with some rare siliceous Diatomaceæ.

The Chalk-with-flints is rich in various species of *Micraster* and *Cidaris* (see Pl. XI); *Lima spinosa*, *L. Hoperi*, *Rhynchonella plicatilis*, *Inoceramus Cuvieri* are common, together with teeth of *Otodus* and *Ptychodus*; also branching *Sponges* and *Ventriculites*. The higher beds of the White Chalk are characterised by *Belemnitella*, *Marsupites*, and numerous sponges.

The Upper Chalk of Maastricht is not represented in England. In the North of France it forms a small deposit abutting against the White Chalk at Laversine, near Beauvais; but the most interesting section is at Mont-Aimé, near Sézanne. It there consists of beds of a calcareous travertine capping an isolated hill of White Chalk, and abounds in fossils, mostly in the state of casts and impressions. Amongst the fossils of this zone are *Cerithium Carolinum*, *Cardium pisolithicum*, *Nautilus Danicus*, teeth and bones of Reptiles (*Leiodon*) and Fishes.

Organic Remains. The number of determined species in the English Chalk amounts probably to no fewer than 1200.

Plant-remains, as might be expected, are very rare in the Chalk.

They are confined to a few drifted fragments of Coniferous wood, often drilled by boring Molluscs. In the Upper Chalk this wood is generally encased in flint and silicified. The microscopic Diatoms are marine organisms belonging to the vegetable kingdom; and the Coccoliths also are referred by some naturalists to a vegetable origin.

Foraminifera are extraordinarily abundant, especially in the Upper White Chalk, in some specimens of which Mr. Sorby has estimated that they form ninety per cent. of the bulk of the rock. Above 100 species and notable varieties are known. They mostly belong to such genera as at the present day live from near the shore down to depths of 100 fathoms, though there are some which exist at much greater depths. The most abundant genera are Nodosaria, Dentalina, Marginulina, Cristellaria, Flabellina, Frondicularia, Textularia, Globigerina, and Planorbulina; and amongst the more common species are *Nodosaria Zippei*, *Dentalina communis*, *Cristellaria rotulata*, *C. ovalis*, *Flabellina cordata*, *Frondicularia Archiaciana*, *Textularia globulosa*, *Lituola nautiloïdea*, *Planorbulina ammonoides*, *Globigerina cretacea*, etc.

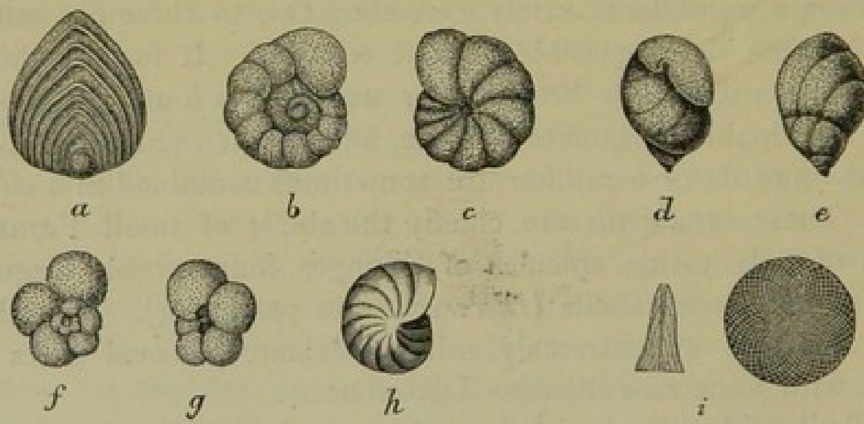

FIG. 151. Foraminifera of the Chalk.
a. Flabellina cordata, Reuss, × 8. *b, c. Planorbulina ammonoides*, Reuss, ×25. *d, e. Bulimina Presli*, Reuss, × 25. *f, g. Globigerina cretacea*, Reuss, × 50. *h. Cristellaria rotulata*, (Lamarck), × 10. *i. Orbitoides media*, D'Orb. interior (sections), of the South of France.

Cœlenterata; Spongidæ. I have already had occasion, in describing the Jurassic strata, to mention the importance of Sponges, both palæontologically and stratigraphically, how they characterise certain Formations in which they abound, and how in some they even contribute largely to the materials of the rock-masses. Further, few organisms are more distinctive of zones of depth. The Calci-sponges, of which there are many Oolitic genera, abound most in shallow waters; whereas the Hexactinellid Sponges, to which belongs the Euplectella of the Japanese seas (whose well-known glassy siliceous skeleton forms so beautiful an object), inhabit, as a rule, waters of considerable depth. To this order belong the larger proportion of the Upper-Jurassic and Cretaceous genera; the common Ventriculitidæ of the Chalk are also closely allied to it. The living genera are confined chiefly to the deep waters of the Atlantic and Pacific Oceans.

The Sponges of the Cretaceous series are, in fact, amongst the most remarkable and abundant of the lower forms of life which flourished during that period[1]. They abound in many of the Lower-Cretaceous strata, are common in the Lower Chalk, and swarm in the Upper Chalk, where the original beds of sponges are often represented by equivalent lines of flint. As the animal matter decayed and passed away, it was often replaced by silica, which has thus preserved, more or less distinctly, the shape, form, and structure of the original life-form. There are cases in which the Sponge has been so perfectly replaced by flint that the silicified fossil retains the nearly perfect outer form of the living organism. In most cases, however, the soft sarcode decayed and the external form is lost, nothing being left of the original sponge structure but the siliceous spicula, which formed its skeletal frame-work. Sometimes these spicules are absorbed or included in the solid amorphous flints; at other times they lie on their surface; while in some instances the mass of siliceous spicula is preserved as a shapeless opaque white powdery substance, enclosed in a surrounding case of flint.

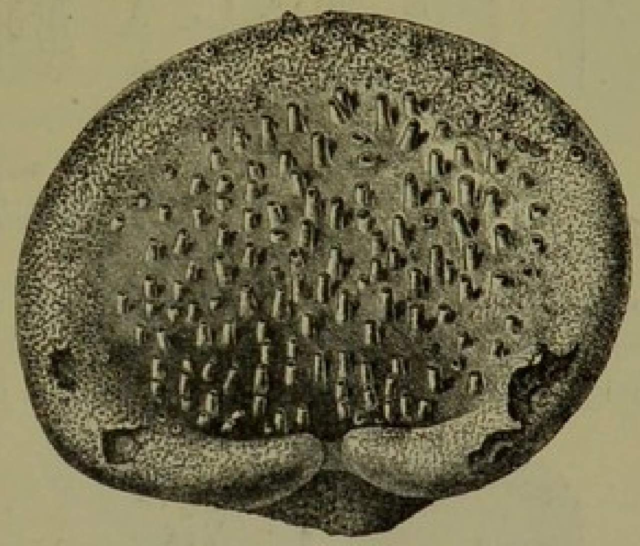

FIG. 152. *Verruculina Reussii*, M'Coy; Flamborough Head.

Lithistid and Hexactinellid sponges chiefly abound in the Chalk; while the former, together with Tetractinellid Sponges, prevail in the Upper and Lower Greensands. Although the form of the Sponge and of its canal system are so rarely preserved, yet as these fossil Sponges are classified according to the character of the minute spicula which enter so largely into the structure of the sponge-skeleton, the geologist is enabled in the absence of the other parts to refer the Sponge remains to their respective orders or families, if not to their special genera. Some of the more characteristic forms of these abundant microscopic objects are here figured. Sometimes the silica of the spicula is replaced by calcite, at others (especially with the Ventriculites of the Lower Chalk) by iron sulphide or peroxide, whilst not unfrequently it is altogether dissolved away and a cavity left in its place[2].

Siliceous casts of minute boring sponges (Clionæ) are common in flints

[1] The reader should consult the fine work on the 'Fossil Sponges in the British Museum,' by Dr. George J. Hinde, F.G.S. I am much indebted to the author for his assistance in the selection of the Sponges for illustration in this and the preceding chapters.

[2] See the remarks on the composition of Chalk and its Sponges by Prof. Rupert Jones, and Prof. Sollas, in Dixon's 'Geology of Sussex,' 2nd edit., pp. 123-131, 287, 448-454.

as thread-like casts of the hollows excavated by the Sponge in Belemnites, and especially in the shells of Inocerami; while a possible gigantic form of Sponge, in structureless flint, known as 'Potstones' or 'Paramoudras,'

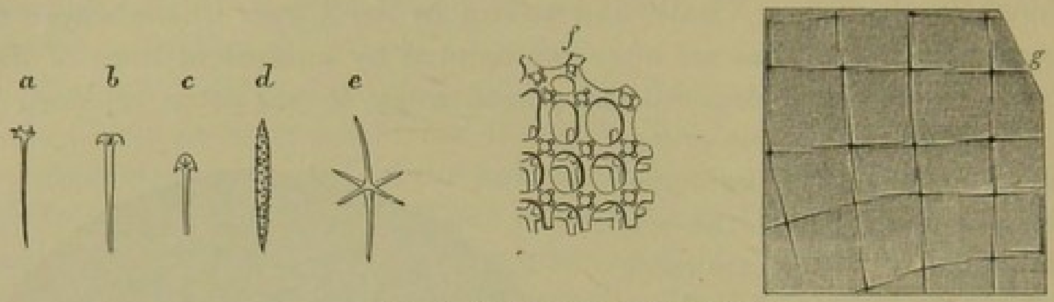

FIG. 153. Spicula of Chalk Sponges. (After Hinde.)
a. Doryderma Roemeri, H. *b, c. Stelletta inclusa*, H. *d. Acanthorapsis intertexta*, H. *e. Hyalostelia fusiformis*. *f. Fragment of the skeletal mesh of Ventriculites*, H. $\frac{10}{1}$. *g. Cincliderma quadratum*, showing portion of the dermal layer, $\frac{30}{1}$.

occurs in the Upper Chalk of Norfolk, and of the North of Ireland. It resembles the existing 'Neptune's Cup,' and is from one to three feet in height. The specimens are found in an upright position, one over another,

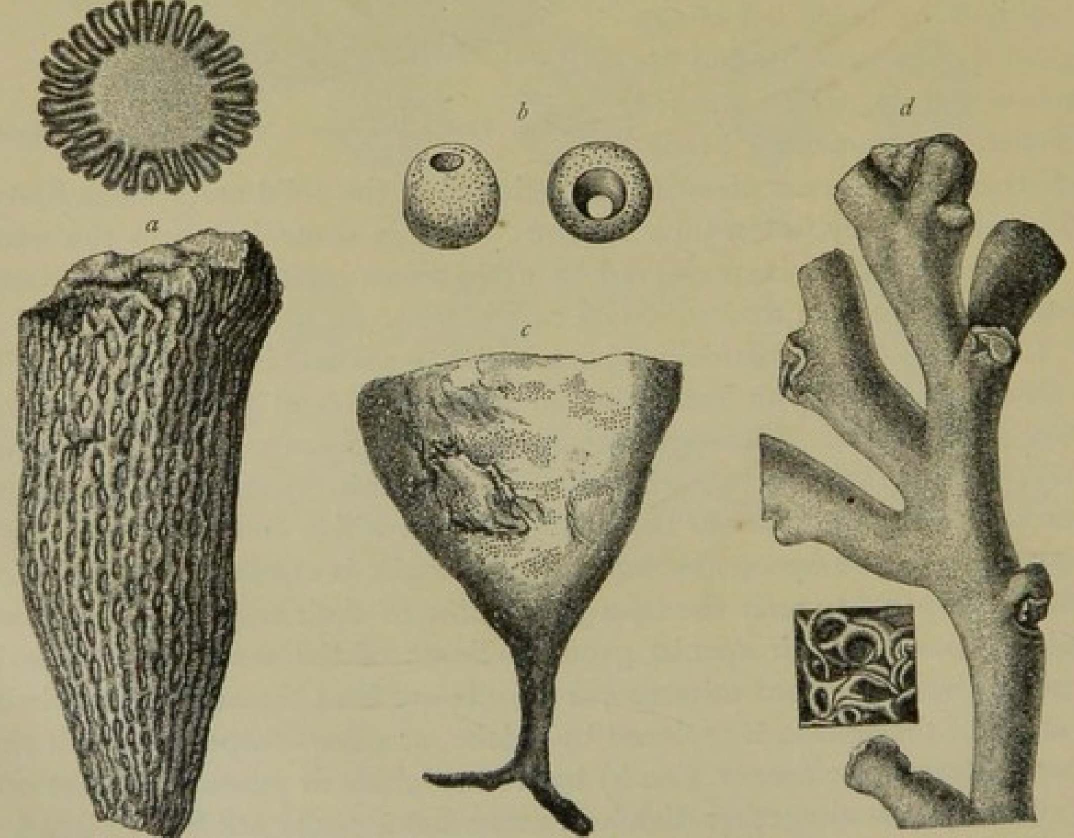

FIG. 154. Sponges, etc., of the Chalk.
a. Ventriculites infundibuliformis, S. Woodward. *b. Porosphæra (Coscinopora) globularis*, D'Orb. *c. Porochonia (Ventriculites) simplex*, T. Smith. *d. Doryderma ramosum*, Mant.

through several successive beds of Chalk, traces of a narrow connecting tube often existing between the several individuals.

The commoner species of Chalk sponges are,—*Ventriculites decurrens*, *V. infundibuliformis*, *Porochonia simplex*, *Verruculina* (Manon) *Reussi*, M^cCoy, *Cephalites Bennettiæ*, Mant., *Doryderma ramosum*, Mant., *Thamnospongia* (Polypothecia) *clavellata*, *Plocoscyphia* (Choanites) *flexuosa*.

Corals are not uncommon, but they mostly belong to the smaller, single, deep-sea forms, and not to the reef-building corals. A few small branching corals are met with in the White Chalk. Professor P. M. Duncan says that the Chalk corals are all of a kind whose representatives, for the most part, live at a depth of from 500 to 600 fathoms. Amongst the characteristic forms are—*Caryophyllia cylindracea*, *Parasmilia centralis*, *Synhelia Sharpeana*, and *Axogaster cretacea*.

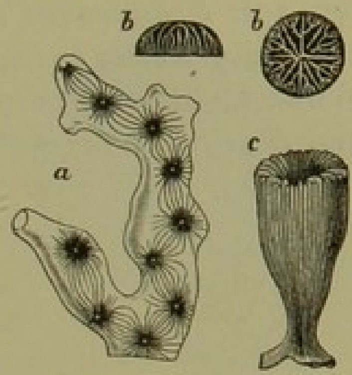

FIG. 155. *a. Synhelia Sharpeana*, M. Edw. *b. Stephanophyllia Bowerbankii*, M. Edw. *c. Parasmilia centralis*, Mant.

Echinodermata are abundant fossils at many geological periods, but it is in the Chalk that their remains are found in greatest variety and beauty. Echinoidea of the genera Micraster, Diadema, Cardiaster, Discoidea,

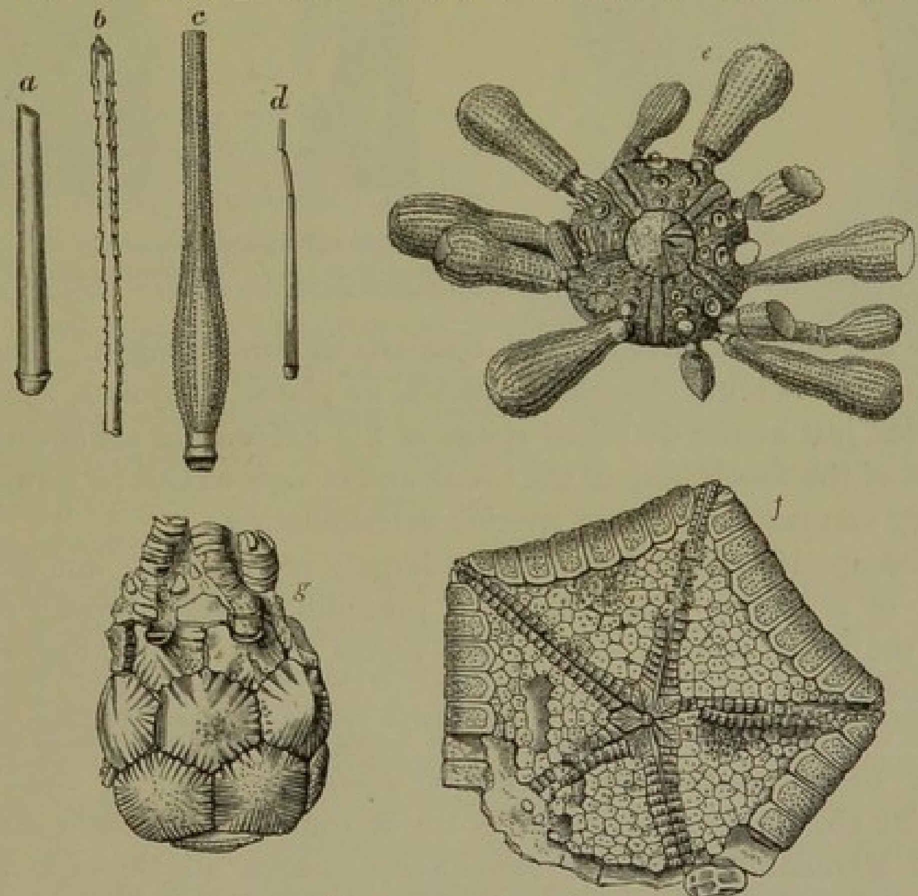

FIG. 156. Echinodermata of the Chalk. (After Dixon.)
a. Cyphosoma variolare, Goldf. *b. Cidaris perornata*, Forb. *c. Cidaris sceptrifera*, Mant. *d. Salenia geometrica* (?), Ag. *e. Cidaris clavigera*, König. *f. Goniaster* (*Goniodiscus*) *Parkinsoni*, Forb. *g. Marsupites ornatus*, Mill.

Cidaris, and Salenia, are especially abundant and characteristic. It is customary to find them partly or entirely filled with flint[1], while at other

[1] These casts are often met with on the surface of the ground and in beds of gravel, where owing to exposure to the action of the surface waters, the calcareous test has been removed, and the siliceous cast of the interior alone remains.

times the flint protrudes through the apertures. *Holaster lævis*, *Discoidea cylindrica* (Pl. XI, fig. 9), and *Salenia gibba*, characterise the Lower Chalk; and *Micraster coranguinum* (Pl. XI, fig. 14), *Ananchytes ovatus* (Pl. XI, fig. 13), *Echinoconus albogalerus*, *Cidaris clavigera*, and *Holaster planus*, especially belong to the White Chalk. Amongst the Crinoids of the Upper White Chalk are the peculiar *Marsupites*, the range of which is very local, and *Bourgueticrinus*, which is much more widely spread: and among the

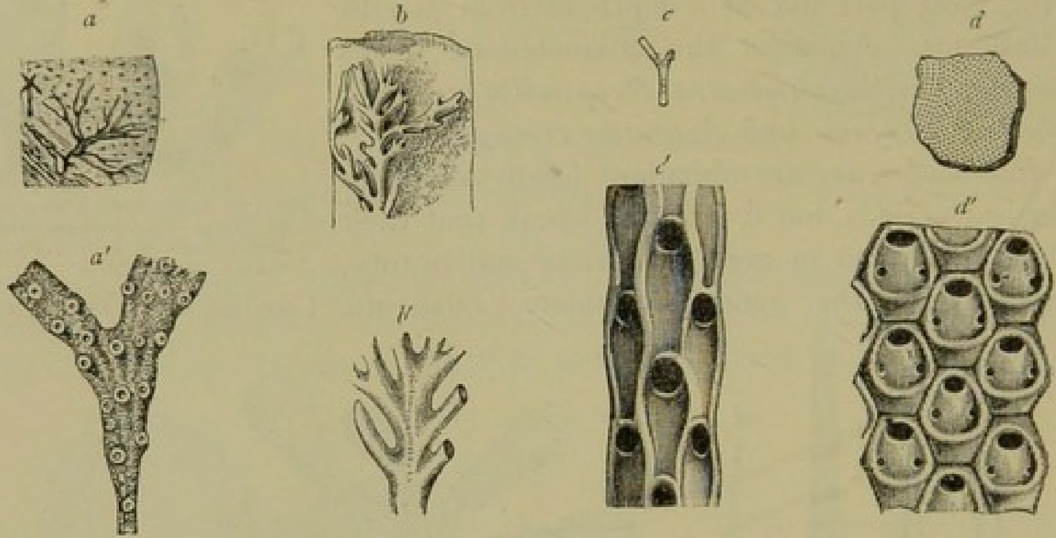

Fig. 157. Polyzoa of the Chalk, nat. size (upper row) and enlarged (lower row).
a, a'. Proboscina ramosa, Mich. *b, b'. Homœosolen ramulosus*, Mant. *c, c'. Vincularia regularis*, D'Orb. *d, d'. Escharina oceani*, D'Orb.

Star-fishes *Oreaster*, *Goniaster*, and *Goniodiscus* are common. They are rarely found entire; but detached ossicles, or plates and joints, abound in certain zones, just as the detached spines of the Echinoidea are amongst the commonest of the fossils both of the Chalk and of various Oolitic formations, though they can rarely serve for specific determination.

The Decapodous Crustacea are not largely represented; but they are, as a rule, of a higher order than the preceding Oolitic types. Of the Lobsters, the most marked species are *Clytia Leachii* (Fig. 159, *c*), and of the Crabs, *Platypodia Oweni*.

Of the Cirrhipedia, several species of *Scalpellum* are not uncommon in the Lower Chalk, and some species of *Pollicipes* occur in the Upper Chalk. The *Ostracodous Crustacea* occur in some of the Chalk strata in very great abundance. *Bairdia subdeltoidea* ranges all through, and is accompanied by *Cythereis ciliata*, and especially by *Cytherella ovata*.

Polyzoa, of beautiful patterns, are plentiful in the Upper Chalk. Many are free forms, but others are parasitic, and occur constantly attached to the tests of Micraster, Ananchytes, Galerites, etc. The species of most frequent occurrence are *Proboscina ramosa*, *Stomatopora ramea*, *Diastopora Sowerbyi*, *Idmonea cretacea*, *Desmopora semicylindrica*, *Petalopora pulchella*, *Vincularia regularis*, *Escharina oceani*, etc.

The Chalk is rich in *Brachiopoda*; *Crania Ignabergensis*, *Terebratula* *carnea*, *T. biplicata*, *T. semiglobosa*, *Rhynchonella plicatilis*, and *Rh. latissima* have a wide range through all the divisions. *Terebratulina gracilis* marks a zone of the Lower Chalk.

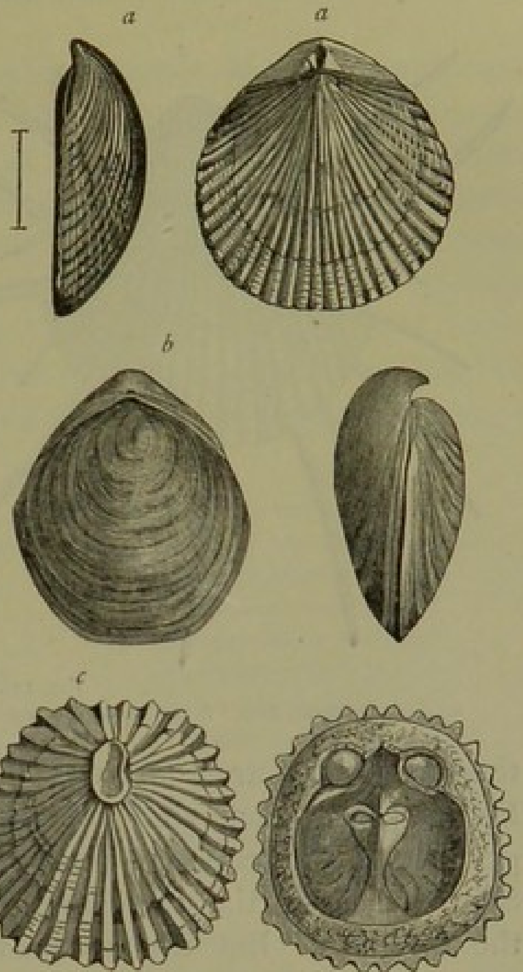

FIG. 158. *a. Terebratulina gracilis*, Schlot. *b. Terebratula carnea*, Sby. *c. Crania Ignabergensis*, Retz.

The *Monomyarian Bivalves* are very characteristic; the commoner species in the White Chalk being *Inoceramus Lamarckii*, *I. Cuvieri*, *Lima spinosa*, *L. Hoperi*, *Pecten nitidus*, *P. cretosus*; and of the Lower Chalk—*Plicatula inflata*, *Lima aspersa*, *Pecten Beaveri*, *P. orbicularis*. Fragments of the shell of the large *Inoceramus Cuvieri* are extremely common in the Chalk-with-Flints. Some years ago, the late Mr. Richard Meason showed me quite a colony of them, apparently in the position in which they had lived, exposed on the roof of a heading in a chalk-pit at Grays-Thurrock. The roof, which was formed by the plane of bedding of the strata, was literally plated over a surface of several square yards with the large flat valves of this shell. The detached needle-like prisms of the decayed Inocerami often form a component part of the Chalk itself, and have at times been mistaken for sponge spicules.

Dimyarian Bivalves are less common. The chief species are *Leda pulchra*, *Unicardium Ringmeriense*, and *Pholadomya decussata*.

Gasteropoda are comparatively scarce. Specimens of *Rostellaria Parkinsoni* are met with in the Lower Chalk, and *Pleurotomaria perspectiva* ranges all through. In the hard bed between the Upper and Lower Chalk, Gasteropods are however common, although they are almost always in the state of casts. The species of most frequent occurrence are *Natica canaliculata*, *Solarium ornatum*, *Pleurotomaria perspectiva*, with *Scaphites æqualis*, *Baculites anceps*, etc.

Dibranchiate Cephalopoda are common in all the divisions of the Chalk; but the *Tetrabranchiates* are chiefly confined to the lower divisions, where they are often extremely abundant, especially in the Chalk-marl and Chloritic Marl,—the characteristic species being *Ammonites Mantelli*, *A. varians*, *A. laticlavius*, *A. Sussexensis*, *A. Rothomagensis*, *Nautilus elegans*, and *Turrilites costatus*.

Fishes. In the Lower Chalk especially the remains of Fishes are common, and are often in a remarkable state of preservation. Not only the teeth and various bones, with the scales, but sometimes the skin and

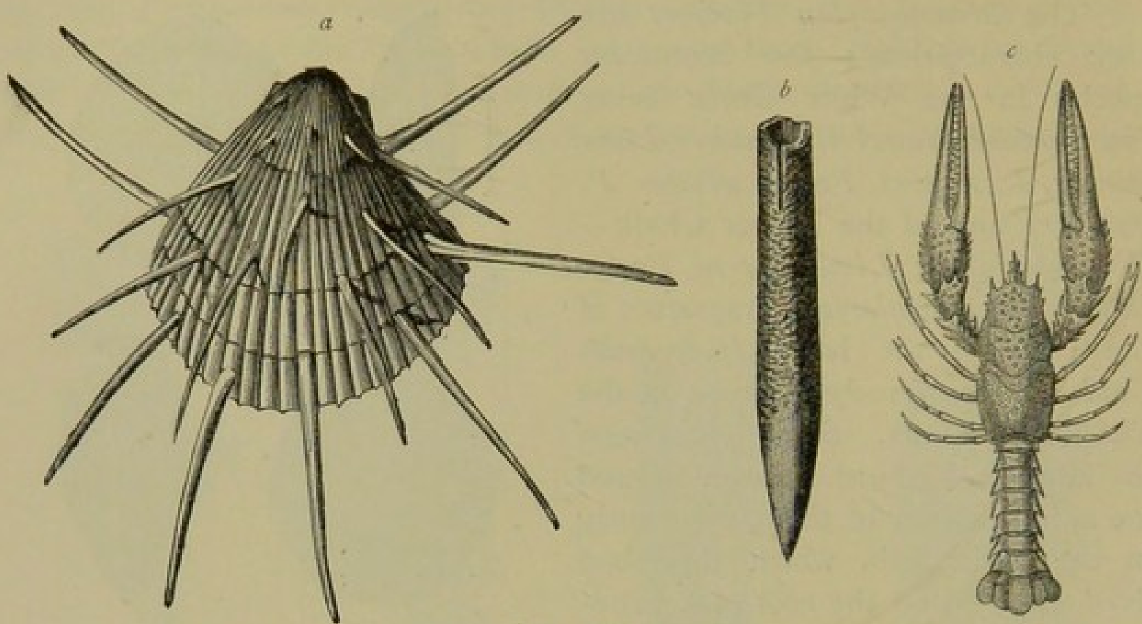

FIG. 159. Fossils of the Chalk.
a. Lima spinosa, Sby. *b. Belemnitella mucronata*, Schlot. *c. Clytia Leachii* (restored by Prof Reuss).

the air-bladder are preserved. The peculiar jaw-plates of the Chimeroid Fishes (Edapodon, etc.) are rare. Of the large Ray (Ptychodus), the peculiar palatal teeth are common and characteristic. The teeth of various Sharks, such as the Otodus (*O. appendiculatus*), Lamna, etc., abound in all the divisions. But the circumstance of greatest interest connected with the Fishes of this period, is that we here meet with the first Teleostean

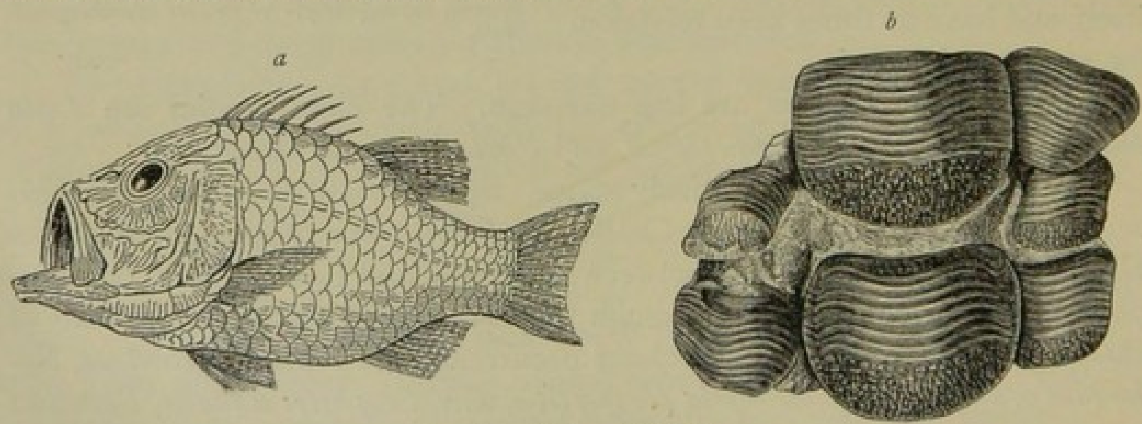

FIG. 160. Fishes of the Chalk.
a. Beryx Lewesiensis, Mant. *b. Palatal teeth of Ptychodus decurrens*, Ag., nat. size.

or bony Fishes—the order which now constitutes the great bulk of existing Fishes. Of Beryx, of which there are five species living in the tropical Atlantic and seas of Japan (at a depth of 345 fathoms), nearly entire specimens are not uncommon, and occur both in the Lower and the Upper Chalk.

Reptilian remains are comparatively scarce. A species of *Mosasaurus*

(*M. gracilis*) has been found in the White Chalk of Kent and Surrey. Species of *Ichthyosaurus* (*I. campylodon*) and of *Plesiosaurus* (*P. Bernardi*) still survived; but the long course of these ancient Saurian forms ends with the Chalk.

Palæontological Zones. A certain number of species amongst the Echinodermata, the Brachiopoda, the Mollusca, and the Cephalopoda have a wide range through the whole of the Chalk, but other species are confined to definite zones, or have their maximum development in those zones. These palæontological divisions have of late years been worked out in considerable detail, and are found to coincide very closely with those previously established for the Chalk of the North of France. Between the Isle of Thanet and Folkestone the Chalk, according to Whitaker, Hébert, Price, and others, is divisible into the following groups and zones:—

Senonian ...	Chalk with flints, of Margate, ...	Zone of *Micraster cor-anguinum.*
	" " Ramsgate, Broadstairs,	" " *cor-testudinarium.*
	" " and St. Margaret ...	" *Holaster planus.*
Turonian ...	Chalk of Dover	" *Inoceramus labiatus.*
	Chalk without flints	" *Terebratulina gracilis.*
Cenomanian ...	Nodular Chalk	" *Cardiaster pygmæus.*
	Grey Chalk	" *Belemnitella plena.*
		" *Holaster subglobosus.*
		" *Ammonites Rothomagensis.*
		" " *varians.*
	Chalk-Marl	" *Plocosyphia æqualis.*
		" *Stauronema Carteri.*

In the Isle of Wight, Dr. Ch. Barrois[1], who bases his zones on the stratigraphical divisions of Bristow, Ibbetson, and Whitaker, makes the palæontological zones from the summit to the base of the Chalk to correspond as under:—

White Chalk with *Belemnitella mucronata*	265 ft.
White Chalk with *Micraster cor-anguinum*	525 ft.
White Chalk with *Micraster cor-testudinarium*	165 ft.
White Chalk with *Holaster planus*	65 ft.
Chalk-Marl with *Terebratulina gracilis*	65 ft.
Chalk-Marl with *Inoceramus labiatus*	130 ft.
Glauconiferous Chalk with *Turrilites* and *Scaphites æqualis*	115 ft.
Chloritic Marl with *Ammonites laticlavius.*	6 ft.
Upper Greensand with *Ammonites inflatus*	...

In Surrey, Mr. Caleb Evans[2] has given a section of the line from Croydon through the North Downs to Oxted, which shows the following succession:—

Upper Chalk, 250 ft.	Purley beds	Zone of *Micraster cor-anguinum.*
	Riddlesdown beds ...	" " *cor-testudinarium.*
	Kenley beds	" *Holaster planus.*

[1] 'Géol. de l'Isle de Wight,' 1875.

[2] 'Proc. Geol. Association,' for 1870.

Middle Chalk, 75 ft.	Whiteleaf beds	Zone of *Terebratulina gracilis* and *Inoceramus Brongniarti*.
Lower Chalk, 190 ft.	Upper Marden beds ...	„ *Inoceramus labiatus*.
	Lower Marden beds ...	„ *Belemnitella plena*.
	Oxted beds	„ *Holaster Trecensis* and *Am. varians*.

In Buckinghamshire and Cambridgeshire the following divisions have been established by Messrs. Whitaker, Jukes-Browne, and Penning:—

Upper (base of) ...	Chalk-with-flints ...	Zone of *Micraster cor-bovis*.
Middle	Chalk-Rock	„ *Holaster planus*.
	Soft Chalk	
	Chalk with few flints ...	„ *Terebratulina gracilis*.
	Hard Chalk	„ *Rhynchonella Cuvieri*.
	Melbourne Rock ...	„ *Inoceramus labiatus*.
Lower	Grey Chalk	„ *Holaster subglobosus*.
	Totternhoe Stone ...	
	Chalk-Marl	„ *Rhynchonella Martini*.
	Coprolite Bed.	

According to Professors Phillips and Blake the subdivisions of the Chalk in Yorkshire are:—

Upper division, 500 ft.	Chalk without flints ...	Zone of *Belemnitella mucronata*, *Marsupites*, and *Sponges*.
	Chalk with flints ...	„ *Micraster cor-anguinum*.
Lower „ 300 ft.	Chalk with nodular flints	„ *Inoceramus mytiloides*.
	Grey Chalk	„ *Holaster subglobosus*.
	Red Chalk	„ *Belemnites minimus*.

The Yorkshire Chalk is remarkable for the beautiful state of preservation of its silicified sponges (see Fig. 152, p. 291).

Although the Chalk is so pure and free from extraneous matter, it occasionally contains pebbles and blocks of foreign rocks. A boulder of decayed granite, with decomposed felspathic fragments and a small mass of quartzose sand, were found in a chalk-pit at Purley near Croydon. Subsequently, a small block of impure coal was met with in making the line between Canterbury and Dover. It is not uncommon also to find occasionally pebbles of white quartz in the Chalk[1]; while in the Coprolite bed at the base of the Chalk of Cambridgeshire pebbles and small boulders of various felspathic and palæozoic rocks, derived no doubt from some adjacent old land, are met with.

Owing to the great dimensions, uniform lithological character, and extreme powers of imbibition of the White Chalk,—combined with its lines of fissure connected with the jointing and the horizontal and oblique lines of flints, and the extensive bare surfaces this Formation presents,—a large proportion of the rain that falls upon it passes underground and is there stored for delivery during long periods of time, giving rise, as it escapes, to numerous springs of great permanence. (Vol. I. p. 166.)

[1] Some of the small pebbles may have been dropt by marine reptiles, which, like the crocodile of the present day, seem to have been in the habit of swallowing such pebbles.

Continental Equivalents of the Upper-Cretaceous Series. Strata of this age have a very wide range throughout Europe, though they are often hidden by Tertiary strata, and, in North-Eastern Europe, by drift sands and gravels, and boulder-beds. In this range they show not only great variations in petrological structure, but they also present marked differences in their fauna. Still there are generally a few common characteristic forms having a wide range, while, where similar lithological characters are repeated or maintained, the species show a remarkable persistence.

Whereas the Upper-Cretaceous strata consist in England and the North of France essentially of Chalk, with only a small proportion of subordinate glauconiferous sands at its base, they consist in Central Europe mainly of compact sandstones, and in Southern Europe of massive limestones. These differences are accompanied by corresponding differences in the organic remains.

It will be therefore more convenient to take each of these petrographical areas separately rather than follow the geographical grouping we have adopted for the other formations, and take for each region a few typical centres, with the more noticeable local features.

The Region of White Chalk. The typical White Chalk extends from England through the North of France, South Belgium, East Holland, Westphalia, Hanover, Denmark, South Sweden, the Coast of Pomerania, Poland, Silesia, Russia,—then in one direction to the Crimea, and, in the other, with intervals, to the South of the Ural Mountains. The pure earthy 'White Chalk' is not met with outside these districts.

We may take as the type of this regional section of the Chalk Series the divisions established in the Paris Basin, where they have been worked out in great detail by the French geologists. The following is a summary of their chief lithological characters, and of the succession of their palæontological zones. The fossils are on the whole very similar to those of the corresponding beds of England. The stratigraphical divisions are those of M. A. D'Orbigny, while the subdivisions and palæontological zones are, in the main, those of Professor Hébert.

THE UPPER-CRETACEOUS ROCKS OF NORTH-WESTERN FRANCE.

	PETROLOGICAL ZONES.	PALÆONTOLOGICAL ZONES.
Danian ...	Calcaire Pisolitique of Laversine and Mont Aimé	Zone of *Nautilus Danicus.*
	Calcaire à Baculites of the Cotentin ...	" *Baculites anceps.*
Senonian ...	White Chalk with flints of Meudon, Epernay, &c.	" *Belemnitella mucronata.*
		" " *quadrata.*
	Chalk Cliffs east of Dieppe	" *Micraster cor-anguinum.*
	Chalk Cliffs west of Dieppe	" " *cor-testudinarium.*
Turonian...	Upper (flinty) part of Cape Blanc-Nez	" *Holaster planus* and *Micraster breviporus.*
	Light yellow micaceous Chalk with cherty flints of Touraine (Craie tufeau)	" *Terebratulina gracilis.*
	Marly Chalk (Craie marneuse) ...	" *Inoceramus labiatus.*

Cenomanian.	Sands and Sandstones of the 'Maine[1]'	Zone of	*Ostrea columba* and *Anorthopygus orbicularis.*
	Lower Beds of Cape Blanc-Nez ...	,,	*Belemnites plenus.*
	Chalk of Rouen (Craie glauconieuse)	,,	*Ammonites Rothomagensis* and *Pecten asper.*
	Green sands of Havre	,,	*Ammonites inflatus.*

In the South of Belgium[2], the same general divisions hold good, though modified to a certain extent by the circumstance that we are there on the old shore-lines of the Cretaceous sea at the time the deposition of the Cenomanian strata was going on. The divisions are mainly those of Dumont, or of Cornet and Briart:—

THE UPPER-CRETACEOUS STRATA OF BELGIUM.

Maëstrichtian	Tufaceous Chalk of Ciply	Zone of	*Hemipneustes striato-radiatus.*
	Malogne Conglomerate	,,	*Thecidea papillata.*
Senonian ...	Phosphatic Chalk of Ciply, and coarse Chalk of Spiennes	,,	*Trigonosemus Palissi.*
	White Chalk of Nouvelles	,,	*Belemnitella mucronata.*
	,, of Obourg	,,	,, *quadrata.*
	,, of St. Vaast	,,	*Micraster cor-anguinum.*
Turonian ... (*Nervian.*)	Flinty beds of St. Denis (Rabots) ...	,,	*Terebratulina gracilis.*
	Marly Chalk (Dièves and Fortes-Toises of Hainaut)	,,	*Inoceramus labiatus.*
Cenomanian (*Hervian.*)	Glauconiferous beds (Tourtia) of Mons	,,	*Belemnites plenus.*
	Conglomerate bed of Tournay and Montigny-sur-Roc (Tourtia) ...	,,	*Holaster subglobosus.*
	Calcareo-ferruginous Sandstone (Sarrazin) of Bellignies	,,	*Pecten quinquecostatus.*
	Meule de Bracquegnies...	,,	*Trigonia dædalæa.*

In this area, as in Touraine, the flints occur much lower in the series than in England. In the Nervian, they form huge, grey, opaque, banded blocks and beds. Another point to notice is the extreme variation in the thickness of all the subdivisions. This is owing to the circumstance just mentioned, that we are here on an old shore-line formed by the range of the Ardennes; and, as the coast of this old land was slowly submerged, its irregularities of surface were gradually filled up and levelled. In consequence of these conditions the Cenomanian strata often thin out in many places, or are represented by old beaches and pebble-beds, formed either as the land was temporarily stationary between subsidences, or during the gradual encroachment of the sea.

It is thus that the Meule de Bracquegnies fills a depression some 600 feet deep amongst the Palæozoic rocks, and has the beds at its base strewed with the pebbles derived from those rocks. In the same way the Chalk of Mons fills another valley about 800 feet deep in the Carboniferous rocks. Thus, while in the centre the Chalk has a thickness of 700 to 800

[1] Wanting in the more northern departments, and in England.

[2] See also Gosselet's 'Esquisse Géologique du Nord de la France,' 2e Fascicule, 1881.

feet, at a few miles distance it thins out altogether. This gulf and the adjacent coasts were gradually silted up, and beach-lines and shore-deposits formed at successive intervals. Overlying the Meule de Bracquegnies is the shore deposit known as the 'Sarrazin de Bellignies.' A little higher comes the Tourtia of Tournay and of Montigny-sur-Roc, which lie above the zone of *Pecten asper* and *Holaster subglobosus*. At the base of the Danian in the vicinity of Mons is another conglomerate, the 'Poudingue de Malogne,' besides one or two more local beds.

Another point of interest connected with the Belgian Chalk is the great development of phosphatic beds in the Mons basin. The brown chalk of Ciply, which forms the top bed of the Senonian, and attains a thickness of 80 to 100 feet, contains 10 to 14 per cent. of phosphoric acid[1]. The phosphate occurs under two forms,—(1) in the unaltered beds, and (2) in beds which have been exposed to the action of the surface-waters. In the latter a large proportion of the carbonate of lime has been dissolved out of the rock, leaving an insoluble brown powdery substance containing as much as from 45 to 67 per cent. of phosphate of lime[2]. M. Cornet ascribes the presence of the phosphoric acid in this rock to a circumstance analogous to that which now, at the change of the monsoon, leads to the throwing up by the sea of millions of all kinds of dead fish on the coast of Perim and of Aden, and which thus furnish periodically an accumulation of animal substances rich in tribasic phosphates.

The pebble-beds of the Chalk (Tourtia) are generally rich in fossils. M. D'Archiac[3] has described above 300 species from the Tourtia of Tournay and Montignies-sur-Roc. At Tournay, about one quarter of the fossils consist of a single species of brachiopod—the *Terebratula Nerviensis*. Amongst other characteristic fossils are *Astarte striata*, *Terebratula biplicata*, etc.

It is in the Belgian also that the Danian stage first acquires importance. In the neighbourhood of Mons it is about 70 feet thick and rests on an eroded surface of the underlying beds. In the valley of Liége and at Maëstricht it attains a thickness of 300 to 400 feet, and consists of a light yellow calcareous freestone full of Polyzoa (*Eschara*, *Idmonea*, etc.) and Foraminifera, and is also rich in Crocodilian and Mosasaurian remains (*Mosasaurus Camperi*) and Fish. Amongst other characteristic fossils are *Baculites Faujasi*, *Thecidium papillatum*, *Hemipneustes striato-radiatus*,

[1] M. Cornet considers that the Phosphatic beds and the underlying coarse Chalk of Spiennes form a local and separate division between the Danian and Senonian. Some of the fossils abounding in parts of the phosphatic beds are of the same species as those of the underlying White Chalk, while there are others which are only found in the Danian. In 1885, the nearly entire skeleton of a new Saurian (*Hainosaurus Bernardi*), measuring 50 feet in length, was found in the lower part of the Phosphatic Chalk.

[2] See M. Cornet's paper in 'Quart. Journ. Geol. Soc.,' vol. xlii. p. 325.

[3] 'Mém. Soc. Géol. de France,' 2e Sér., vol. ii.

Cidaris Faujasi, *Belemnitella mucronata*, together with species of Hippurites and Sphærulites, and Gasteropods of such genera as Voluta, Fasciolaria, Mitra, Emarginula, etc., generally found only in Tertiary strata.

It is again in a depression of Palæozoic rocks that the small Cretaceous basin of Aix-la-Chapelle is situated. The sands and sandstones (300 feet thick) at the base of this series are now referred to the lower part of the Senonian. They are remarkable for their abundant dicotyledonous and cryptogamic flora; six species of Sequoia, and five of Dryophyllum, together with twenty-two species of Pteridoleimma have been described by De Bey and Von Ettingshausen.

In Westphalia and Hanover, the Chalk of Haldem, with *Belemnitella mucronata* and *B. quadrata*, corresponds with the Upper White Chalk-with-flints. Beneath this are the well-known marls of Emsch (Emscher-Mergel), which attain a thickness of 1500 to 1600 feet and are of Lower Senonian age. The characteristic fossils are *Ammonites tricarinatus*, *Turrilites plicatus*, and *Inoceramus cardissoides*. At their base are beds with *Inoceramus Cuvieri*.

The Danian of Faxoe is from 40 to 50 feet thick, and consists almost entirely of fragments of Corals and Polyzoans, with *Nautilus Danicus*, *Belemnitella mucronata*, *Baculites Faujasi*, *Cypræa bullaria*, etc.

The White Chalk thence sweeps round by the coast of Pomerania, through Poland and Podolia into Southern Russia, though, owing to the covering of drift and newer strata, it is but little exposed. According to Murchison[1], the pure White Chalk then 'reappears with exactly the same aspect and composition' as in England, and is, as a whole, marked by similar groups of organic remains. In Poland there are chalky beds containing *Micraster cor-anguinum*, *Terebratula carnea*, etc., while in the purer White Chalk of Russia, there are found *Ostrea vesicularis*, *Inoceramus Cuvieri*, *Belemnitella mucronata*, *Lima Hoperi*, and other well-known Upper-Chalk fossils.

On the northern borders of this Cretaceous district, the Chalk overlies directly, as in Belgium, Palæozoic (mostly Carboniferous) rocks, forming, as it does there, small basins in depressions of the older rocks; whilst southward it acquires greater development and thickness. At Volsk there is about 200 feet of Chalk with Belemnites, while at Lugan, on the borders of the Donetz coal-field, it has been found to exceed 630 feet in thickness. When the White Chalk becomes thinner, the Green Sands, which here occur both in the upper and lower part of the series, acquire greater importance. From Donetz, the Chalk passes in one direction southward, being found in the Crimea, and in another direction eastward, it being again met with on the banks of the Ural, whence it extends to the confines of Asia.

The Region of the Sandstones. While the White Chalk forms

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[1] 'The Geology of Russia in Europe,' vol. i. p. 263 *et seq.*

the northern belt of the Cretaceous area, the centre of that area consists of rocks having an altogether different lithological type. In Saxony, Bohemia, and Eastern Germany, strata of Albian and Neocomian age are wanting, and Upper-Cretaceous strata rest unconformably on Jurassic or older rocks. The series here, however, contains no true White Chalk, although some of the subdivisions (the Upper Pläner) contain as much as 75 per cent. of carbonate of lime. Instead of the soft white homogeneous strata, with the rounded hills and deep combes of the more western districts, we find in this part of Central Europe an enormous development of hard massive, quartzose, coloured sandstones, forming those bold bluffs and steep ravines and passes which so much contribute to the beauty of the scenery in Saxon Switzerland. The following are the broad divisions of this the quartzose type of the Cretaceous series as established by Geinitz, Gümbel, Dunker, Reuss, Credner, and other German geologists.

UPPER CRETACEOUS STRATA OF SAXONY AND BOHEMIA.

Senonian ...	**Upper Quadersandstein** — compact sandstones (of Schneeberg) with very little calcareous matter and few fossils	Zone of *Inoceramus Brongniarti* and *Asterias Schultzei.*
	Marls of the Quader	,, *Baculites anceps* and *Micraster cor-anguinum.*
Turonian ...	**Upper Pläner or Pläner-Kalk**—a sandy calcareous rock with beds of marl (marls of Strehlen)	,, *Lima spinosa* and *Scaphites Geinitzi.*
	Green sands and sandstones of Copitz and Mallnitz	,, *Inoceramus Brongniarti* and *Ammonites peramplus.*
	Middle Pläner—white and ferruginous sandstones, sometimes calcareous (beds of Melnick and Reinhauser) ...	,, *Inoceramus labiatus* and *Ostrea vesicularis.*
Cenomanian.	**Lower Pläner-Kalk** or marls, with subordinate cherts and conglomerates (Regensburg)...	,, *Pecten asper* and *P. æquicostatus.*
	Lower Quadersandstein — light-coloured compact sandstones, sometimes glauconiferous...	,, *Exogyra columba,* and dicotyledonous plants.

Especial interest attaches to the Cenomanian strata, inasmuch as they present here the first appearance in the European area of a Dicotyledonous vegetation. Up to the end of the Wealden, the plant-remains consisted entirely of Cycads, Conifers, and Ferns. Here we come upon a well-established and well-developed angiospermous Flora. In the Lower Quadersandstein of Niederschöna and some other localities, impressions of leaves referred to Credneria, Hymenea, Aralia, Hedera, Acer, Magnolia, Laurus, etc., are found in considerable abundance. The first of these genera is extinct, some of the others now live only in more southern regions, while others still live in the same latitudes.

It is in these strata also, in Silesia, that the first Palm—a small species resembling the existing Chamærops—makes its appearance. At the same time, Cycads and some forms of Conifers and Ferns become gradually rarer.

Hippurites are, as in the English Chalk, very rarely met with, though they are not entirely wanting. Amongst those Mollusca which have a very wide vertical range are *Pecten quinquecostatus* and *Inoceramus mytiloides.*

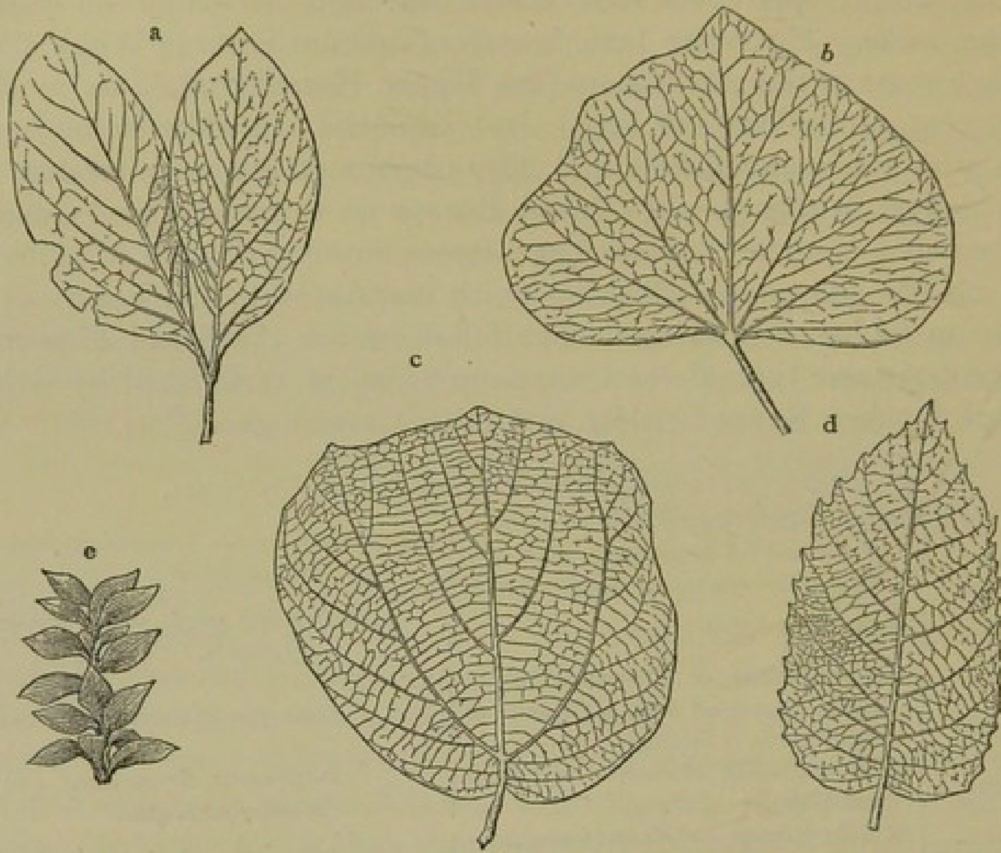

FIG. 161. Cretaceous Plants. (After Saporta.) *a, b.* Cenomanian; *c, d.* Senonian; *e.* Turonian (Toulon). *a. Hymenea primigenia*, Sap. *b. Hedera primordialis*, Sap. *c. Credneria triacuminata*, Hampe. *d. Dryophyllum Haussmanni*, Dkr. *e. Araucaria Toucasi*, Sap.

The Region of Limestones. These form a typical group of rocks equally distinct in their lithological characters as those of the other two regions, and like them characterised by many local and peculiar species, though connected by a few common forms. The development of these rocks is, however, on a larger scale, and wider range. The change becomes apparent immediately south of Touraine. In the Departments of the 'Charentes' the Danian (Dordonian of Coquand) is represented by conglomerates and compact Magnesian Limestones with Hemipneustes, Radiolites, etc.; while the White Chalk is replaced by compact and marly limestones with *Belemnitella quadrata*, *Baculites anceps*, together with species of Hippurites, and the allied Sphærulites, and new species of Ammonites and Echinoidea. Massive limestones with *Caprina adversa*, *Hippurites organisans*, *H. cornuvaccinum*, *Ostrea columba*, *Turrilites costatus*, *Orbitolina concava*, etc., replace the Turonian and Cenomanian strata of the northern districts.

The extinct *Hippuritidæ* and the *Chamidæ*, of which only one genus (*Chama*) survives, abound especially in these rocks. The *Caprina Aguilloni* is a characteristic Turonian species.

But it is in the South of France and the Pyrenees that the type acquires its fuller characters and larger development. It has there been described by MM. Coquand, Hébert, Toucas, Leymerie, and other geologists, who have classified the several groups of strata in the order given in the following table..

UPPER-CRETACEOUS STRATA OF THE SOUTH OF FRANCE.

Danian ...	**Garumnian.**	Limestones of Rognac ...	Zone of *Lychnus ellipticus.*
		Lignites of Fuveau	„ *Cyrena Garumnica.*
	Maëstrichtian.	Marls of Beausset	„ *Hemipneustes radiatus.*
Senonian ...	**Campanian.**	Sandstones and Limestones of Beausset	„ *Belemnitella mucronata.*
	Santonian.	Limestones of Uchaux ...	„ *Hippurites organisans.*
		Sandstones of Mornas ...	„ *Ostrea plicifera.*
Turonian ...	**Provencian.**	Sandstones of Beausset ...	„ *Micraster Matheroni.*
	Angoumian.	Compact Limestones of Beausset	„ *Hippurites cornuvaccinum* and *Sphærulites*
	Ligerian.	Marly Limestones	„ *Inoceramus labiatus.*
Cenomanian.	**Carentonian.**	Upper Limestones	„ *Caprina adversa.*
	Gardonian.	Lower Limestones	„ *Vicarya Renauxiana.*
	Rothomagian.	Sandstones of La Bedoule ...	„ *Pecten asper.*

The coast of Savoy eastward of Nice, of South-Western France, the Maritime Alps and adjacent departments, consist largely of strata of this type. The group in which there is the least change is the Cenomanian, which is in part arenaceous and glauconiferous, and contains amongst other common fossils of the north, *Pecten asper, Ostrea columba, Turrilites costatus, Ammonites Mantelli, A. varians, A. Rothomagensis, Discoidea cylindrica*, etc. In the Turonian and Senonian the change is complete, massive limestones abounding with species of Hippurites, Sphærulites, Radiolites replace the Chalk and Chalk-marls of the north; but still some species, such as *Inoceramus labiatus, Ostrea vesicularis*, and *Cardium Hillanum*, hold their ground amongst a multitude of new forms.

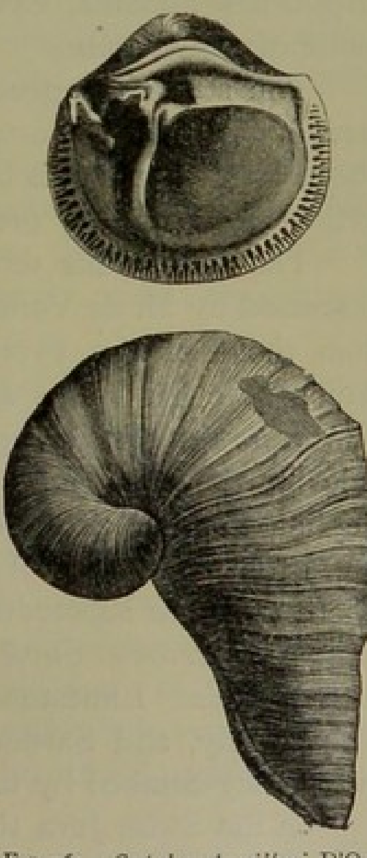

FIG. 162. *Caprina Aguilloni*, D'Orb.

The uppermost division, the Garumnian, the equivalent of the Danian, is remarkable for the great development of fresh-water, estuarine, and lignitiferous beds, which latter attain at Fuveau a thickness of about 1000 to 3000 feet, with seventeen seams of lignite from three to five feet thick. Amongst the fossils of this group are numerous species of Cyrena, Melanopsis, Bulimus, Physa, and Melania, together with a variety of Helix, often in such profusion as to give its name to the bed (*Calcaire à Lychnus*). Others of the Garumnian beds contain Ostrea, Hippurites, Hemipneustes, etc.

The range of the Pyrenees is composed largely of Upper-Cretaceous rocks. The higher divisions of the Cenomanian consist of limestones and slaty shales with Nucleolites, Caprinella, Radiolites, etc., resting on a conglomerate of early Cenomanian age. To these succeed compact limestones, abounding in Hippurites (*H. cornuvaccinum*), Radiolites, Toucasia, Ostrea, etc. of Turonian age. The Senonian consists of limestones, with beds of chert, grey marly limestones, and siliceous limestones, containing species of Ananchytes, Micraster, Holaster, Inoceramus, Ammonites, etc.; while the Maëstrichtian consists of limestones and clays, with Hemipneustes, Orbitoides (*O. media*), Exogyra, Hippurites, etc. Above these, M. Leymerie has shown that there exists a series of fluvio-marine marls, lignites, clays, lithographic limestones, and conglomerates, with species of Micraster (*M. tercensis*), Ananchytes, Cyrena, Actæonella, Ostrea (*O. garumnica*), Hippurites Melania, Cyclostoma, Melanopsis, etc., to which he gave the name of *Garumnian*.

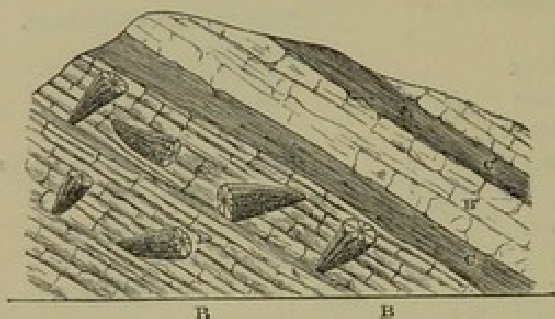

Fig. 163. *Section of Upper-Cretaceous Strata at Villeneuve-d'Olmes (Ariège), showing Hippurites cornuvaccinum in situ* (Hébert).

The strata are generally much disturbed and the fossils badly preserved. Hippurites are, however, often abundant and *in situ*, as in the above section, which is interesting from its showing some of these peculiar extinct shells as they grew in the Cretaceous seas.

The Cretaceous series of the North of Spain, where they have been described by M. de Verneuil, Dr. Barrois and others, are more argillaceous than those of the Pyrenees and attain a thickness of some 3000 feet. Amongst other fossils are the *Micraster cor-anguinum*, *M. cor-bovis*, and *Ostrea larva*. In Portugal, they are, according to Mr. D. Sharpe[1], remarkable for the abundance of Hippurites and Sphærulites, and the absence of Cephalopods and Brachiopods.

From the South of France, the Hippurite-limestones range into Italy, where they are succeeded by sandy red and whitish beds with *Ananchytes ovatus*, *Inoceramus Cuvieri*, and *I. Lamarckii*, and a grey limestone (Scaglia) with fucoids. Limestones with Rudistes extend through parts of central Italy, Sicily, and Sardinia. In the Dalmatian provinces they form bare hills honey-combed by the action of the surface-waters.

In the Swiss Jura the Cenomanian consists of a marly limestone, with

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1 'Trans. Geol. Soc.,' 2nd Ser., vol. vi. p. 107.

Inoceramus Cuvieri, *Holaster sub-globosus*, *Turrilites costatus*, *Ammonites Rothomagensis*, and other of our common fossils.

One noted locality—that of Gosau, in the Austrian Alps—has given rise to much discussion. In the beds there, the fossils are loose and well-preserved, and Gasteropods of genera usually confined to Tertiary strata are numerous; so that they were at first supposed to be of that age. They are also rich in Corals,—Turbinolia, Astræa, Mæandrina, etc. But with these are intercalated beds with Ammonites, Hippurites (*H. cornu-vaccinum*), and other Turonian and Senonian species, which, together with the stratigraphical evidence, leave no doubt of their being Upper-Cretaceous.

The Southern type of the Upper-Cretaceous rocks is continued through much of South-Eastern Europe, including Turkey, Greece, and Candia.

The Mediterranean Area. Hippurite-limestones and other Cretaceous rocks are likewise largely developed in the countries bordering the Eastern Mediterranean. They have been described by Hamilton and Tchihatcheff in Asia Minor, by L. Lartet in Palestine, and by Coquand in Constantine, whence they extend through Algeria to Morocco. In the African area they consist of compact and crystalline limestones, 2000 to 4000 feet thick, with divisions analogous to those of Southern Europe, and with many identical fossils, such as *Ammonites Rothomagensis*, *A. peramplus*, *Ostrea Matheroni*, *Scaphites æqualis*, *Terebratula biplicata*, *Inoceramus labiatus*, *Caprotina ammonia*, *Hippurites organisans*, and various species of Echinodermata. The great Nubian sandstone is probably Cretaceous.

Rocks of this age, with *Exogyra columba*, *Terebratula biplicata*, and *Orbitoides*, also form part of the Lebanon mountains and of the hills around Jerusalem, ranging thence through Arabia to the neighbourhood of Aden; while in Persia, a Hippurite-limestone forms some conspicuous chains of hills.

India. Both the Lower and Upper divisions of the Cretaceous series are represented in the Indian Peninsula, but the former is confined to a small band in Cutch, of which little is known beyond that it contains three species of Ammonites, two of which (*Am. Deshayesi* and *Am. Martini*) are found in Neocomian strata in Europe. On the other hand, the Upper-Cretaceous series is represented, both in Southern and Central India. In the latter area, however, it consists almost entirely of fresh-water beds, intercalated in the earlier basaltic flows of the Deccan, and the fossils, which are rare, being of land and fresh-water species, afford no sufficient terms of comparison for an exact determination of age.

Marine strata possessing a rich and characteristic marine Cretaceous fauna are however well developed around Trichinopoly and Pondicherry, at the southern end of the Peninsula, and again slightly in the Narbada

Valley. They have been fully described by Dr. Stoliczka, and by the authors of the 'Geology of India,' who have shown the striking analogy which the fauna presents to that of Europe, as will be seen by the following table, in which some of the species common to the European area are given.

South-Indian Groups and Fossils.		Related European Divisions.
Arialúr Group	*Ammonites Ootacodensis, Nautilus Bouchardianus, Trigonia scabra, Inoceramus Cripsii, Terebratula biplicata,* etc.	White Chalk or Senonian.
Trichinopoly Group	*Ammonites peramplus, Pholadomya caudata, Cardium Hillanum, Ostrea carinata, Rhynchonella compressa.*	Lower Chalk or Turonian.
Utatúr Group	*Belemnites semicaniculatus, Ammonites rostratus, A. Rothomagensis, Turrilites costatus, Exogyra haliotoidea.*	Chalk-marl to Upper Greensand,—Cenomanian.

A large number (774) of other fossils are found in these Cretaceous strata: amongst them are no fewer than thirty species of Ammonites, sixteen of which are European species. Of the whole Invertebrata, Dr. Blanford estimates that sixteen per cent. consist of forms known to occur in Cretaceous beds in Europe. Nevertheless, he considers that the relationship of the Indian strata is stronger with the South-African than with the European area. He points out that of thirty-five species of Mollusca and Echinodermata found in beds of this age in Natal, twenty-two are nearly identical with the Trichinopoly species. The African beds also, like those of India, are littoral or shallow-water deposits. This and the similarity of forms suggest the continuity of an old coast-line between the two regions, and support the view of a former land connection between South Africa and India during the Gondwána period. This seems confirmed by the circumstance that of the thirteen species of Cretaceous fossils collected in beds of that age in South Arabia, there are three species common to the Bágh beds of the Narbada Valley of Central India[1].

Amongst the few Cretaceous strata of extra-peninsular India are the 'Cardita Beaumonti' beds of Sind and the Olive group of the Punjaub Salt Range. These strata, which consist largely of shales and subordinate limestones, attain in some places a thickness of 5000 to 6000 feet. Near Amri in Sind is a white band of compact limestone with few fossils, but amongst these have been found remains of Hippurites. This discovery is of interest, for, as Dr. Blanford remarks, it shows that this rock may be an Eastern representative of the Hippurite-limestone of Persia, which has so wide a range through Eastern Europe and Western Asia.

Australia and New Zealand. There is in both these countries a considerable development of Cretaceous or Cretaceo-Tertiary strata.

[1] 'The Geology of India,' vol. i. chap. xii.

They comprise in Queensland the 'Desert Sandstones' and a small coal-bearing group, together with some lower beds in which Ammonites and Belemnites, and remains of Ichthyosaurus, have been met with. In New Zealand they form the Ototara beds, the Amuri Limestones, the Island Sandstone, and a Coal-formation, with species of Ancyloceras, Belemnites, Rostellaria, Plesiosaurus, Leiodon, etc.; and an older or Neocomian division, containing large masses of silicified wood, with Belemnites and Trigonia. Unlike the Indian beds of this age, no European species have here been noticed, although many of the genera—Ancyloceras and Leiodon—are characteristically Cretaceous.

The 'Coal-formation' of New Zealand, of Upper-Cretaceous age, contains only brown-coals; but on the West Coast, seams of good bituminous coal are found in sandstones and conglomerates, possibly the equivalent in time of the 'Lower Greensand.' Dr. Hector remarks[1] that all these coal-bearing deposits 'abound with the fossil remains of dicotyledonous and coniferous trees of species closely allied to those represented in the existing flora of the country . . . . associated with Alethopteris, Oleandridum (Tæniopteris), and other forms that are prevalent in the underlying Jurassic beds.'

America. Strata of Cretaceous age are largely developed in North America, ranging along the Atlantic Border of the States from New Jersey southward, again along the Gulf Border and up the Mississippi Valley, and westward through Dakota and Colorado; along the Pacific border and the Coast Range; in the Western provinces of Canada to the Rocky Mountains; and on the shores of Arctic America and North Greenland (see 'Map of the World,' vol. i). The eastern Atlantic series, which seems not to exceed 1000 feet in thickness, consists chiefly of green sands with species of Exogyra, Ammonites, Baculites, Scaphites, and Echinodermata. In Texas, the Cretaceous rocks consist of compact limestones, containing, as in Southern Europe, Hippurites, Caprina, and Nerinæa. In the interior plains and California, the Cretaceous strata, in which sands, sandstones, marls, and shelly limestones predominate, attain a thickness of from 10,000 to 20,000 feet, and contain numerous species of large Ammonites, of Nautilus, Belemnites, Turrilites, Scaphites, Hamites, Inoceramus, Ostrea, Cardium, Holaster, Epiaster, Cidaris; together with Sharks and Ganoid Fishes and enormous Reptiles.

A number of Cretaceous Birds have been described by Marsh from New Jersey and Kansas, including the Hesperornis (a diver five and a half feet high), four species related to the Cormorants, and five to Waders.

The Upper division of the Cretaceous series, both in the United States and Canada, is remarkable for its plants and lignite beds.

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[1] 'Proc. Roy. Soc. New South Wales' for Sept. 1879, p. 73.

Professor Le Conte gives the following table to show the relation of the Western-American to the English Cretaceous series.

		American Groups.	English Groups.	
Laramie, or Transition Beds.		Fort Union	*Wanting.*	
		Judith River		
		Butter Creek		
Cretaceous	Upper	Fox Hill	White Chalk	Cretaceous.
		Fort Pierre		
	Lower	Niobrara	Grey Chalk	
		Fort Benton		
		Dakota...	Upper Greensand	
		Wanting	Lower Greensand	

The American Cretaceous series differs from that of Europe in the magnitude of its Flora and extent of its coal-beds; the great abundance and variety of its Reptiles and Birds; and especially in its extraordinary *Toothed Birds*, described by Professor Marsh, from the Cretaceous shales of Kansas[1].

These peculiar extinct Birds possess characters which separate them so widely from all known recent and fossil forms, that Marsh places them not only in new orders, but in a new sub-class, the *Odontornithes*, which includes those with teeth in grooves, represented by the Hesperornis, and those with teeth in sockets, represented by the Ichthyornis. The possession of teeth in distinct sockets, and of bi-concave vertebræ, with free metacarpals and elongated tail, places the Ichthyornis in close alliance with the Reptiles. There are now ten described species of these Birds.

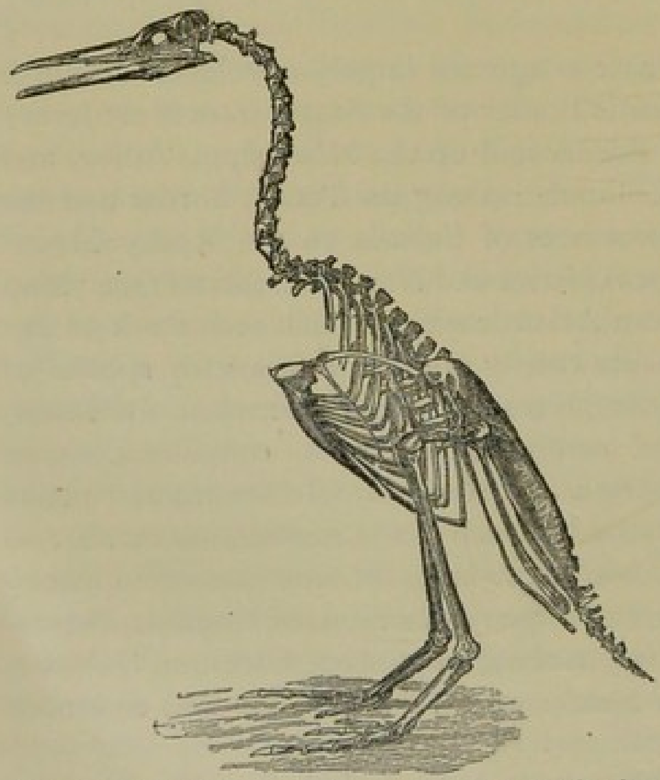

Fig. 164. *Restored Figure of Hesperornis regalis*, Marsh; *from the Upper Cretaceous of Kansas, North America.*

Marsh says[2] of the gigantic diver that it was larger than any known aquatic bird, measuring from the bill to the toes between five and six feet. Its rudimentary wings, like those of the Penguin, prove that flight was impossible, while the powerful swimming legs and feet were peculiarly adapted to rapid motion through water. The tail expanded horizontally, as in the Beaver, and doubtless was an efficient aid

[1] See his magnificent work 'On Extinct Toothed Birds of North America,' Washington, 1880.

[2] 'Amer. Journ. Science and Arts,' vol. x., Nov. 1875.

in diving. That this bird was carnivorous is clearly proved by its teeth; and its food was probably fishes.

The Ichthyornis (*I. victor*) was about the size of a Pigeon, with powerful wings, biconcave vertebræ as in fishes and various extinct reptiles, and teeth set in sockets like those of reptiles, showing that it also was carnivorous.

Great Reptiles swarmed during the Cretaceous period in the North-American area. Of the Mosasaurus alone—great swimming snake-like reptiles, the sea-serpents of the time—fifty species are known. One, the *Mosasaurus princeps*, was from 70 to 80 feet long, with formidable teeth, adapted as in snakes for seizing prey. Enaliosaurs and Dinosaurs were also numerous and of large size, one of the former (*Elasmosaurus platyurus*, Cope) being 50 feet long; while a vegetable-feeding Hadrosaur, with teeth resembling those of Iguanodon, and large massive hind-legs and small fore-legs, as though adapted to stand and walk like birds, must have measured about 28 feet in length.

Of Pterosaurs there were seven species, distinguished from those of Europe by having toothless jaws, probably sheathed with horn, as in birds. One of these measured 25 feet in expanse of wing; and another, 22 feet long, had jaws four feet in length.

Of the forty-eight Chelonians, one—the *Atlantochelys gigas* of Cope—had a length of 15 feet across the extended flippers. Of the Crocodiles, some are of the old Teleosaurian type, and others are related to the Gavial of the Ganges.

The Flora of the Dakota group is considered to be of about the age of the Cenomanian of Europe, as it is analogous to the Flora of that period in Saxony. It consists of above 100 species, of which five are new forms of Ferns, six of Conifers, and the rest angiosperms. The remains are mostly leaves, which occur in a reddish shale and are in a fine state of preservation. They have been described by Lesquereux[1], and are referable, amongst others, to Quercus, Ficus, Platanus, Laurus, Liquidambar, Populus, Salix, Betula, Myrica, Celtis, Sassafras, Diospyros, Azalia, Magnolia, Liriodendron, Paliurus, Rhus, Juglans, Prunus, etc. Many of the genera of the existing arborescent Flora of North America are represented by analogous types. The Cretaceous leaves have, however, generally a thicker coriaceous substance, and greater integrity of the borders. Lesquereux considers that the climatal conditions of temperature under which they flourished were nearly identical with those of the United States in the same latitudes at the present day.

Higher in the series, but yet the one passing conformably into the other, is the great Lignitic group of the Upper-Missouri and the Rocky-

[1] Hayden's Report, 'Geol. Survey Western Territories' for 1876.

Mountain region—a series consisting of shales and sandstones, with marine and fresh-water remains, fucoids, and land plants, and seams of coal,—the whole very similar in general aspect, and almost in magnitude (2000 feet or more), to the coal-bearing strata of the Carboniferous period. The Flora, which has been described in an elaborate Memoir by Lesquereux, consists of about 200 species, and presents an aspect markedly different from that of the Dakota group. We here meet with a profusion of Palms (several species of Sabal, etc.), some of great size, and in places constituting one-fourth of the vegetation. With these are associated species of Ficus, Cinnamomum, Magnolia, Myrica, Quercus, Platanus, Vitis, Viburnum, Cornus, Nelumbium, etc., all of species indicating, according to Lesquereux, a warmer climate than the plants of the Dakota group,—a climate more like that of Florida and Louisiana at the present time. They are plants closely related to those which in Europe we find in Eocene strata.

But while the Flora shows Tertiary affinities, the Fauna combines forms of a true Tertiary character with genera and species which are characteristically Cretaceous, and moreover European, such as *Belemnitella mucronata*, *Nautilus Dekayi*, *Inoceramus problematicus*, *Pecten quinquecostatus*, *Exogyra lateralis*, *Ostrea larva*, *O. vesicularis*, *Cristellaria rotulata*, *Otodus appendiculatus*, *Ptychodus Mortoni*, *etc.* There is further an absence of Mammals, whereas a Dinosaur and a Saurian related to Megalosaurus, both Cretaceous forms, still survived. With species of Cretaceous Ammonites and Marsupites (?) are found Tertiary forms of Physa, Corbicula, Viviparus, Melania, Melampus, Cardita, Crassatella, Typhis, Mitra, Nassa, Conus, Cypræa, Bulla, &c.

Consequently it has been contended on the one side that these beds are of Cretaceous, and on the other, of Tertiary age. They are now, however, generally placed for the present in an intermediate or transition group, which—as the strata are conformable with the Fox-Hill and Pierre (Cretaceous) groups, and there is a survival of Cretaceous forms which only become extinct with the break and unconformity between the Laramie and Alabama beds—is provisionally placed in the Upper Cretaceous series.

In the Dominion of Canada, the Lignitic series forms a vast coal-field between the great lakes and the Rocky Mountains. Dr. Dawson[1] states that it contains some thick beds of coal of good quality, approaching to the characters of true bituminous coal. Little however is known at present of the fossils or stratigraphical details of this important deposit.

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[1] 'Quart. Journ. Geol. Soc.,' vol. xl. p. 381.

CHAPTER XX.

ORIGIN OF THE CHALK.

Preliminary Physical Questions. Oscillations of the Land. Changes of Level and Modifications of the Fauna. Old Beaches of the Cretaceous Period, and Corresponding Zones of Depth. Origin of the Chalk. Profusion of Microscopic Organisms. Mantell. Sorby. Proportion of Silica. Old Beach-Lines. Enlargement of the Original Cretaceous Sea. Origin of Flints: Their Relation to Sponges. Bowerbank. Diatoms. Pseudomorphs. Sponge Protoplasm in Abyssal Waters. Importance of Soluble Silica. Table of Analyses of Chalk. Chert. Chalcedonic Shell-casts. Decrease of Amorphous Soluble Silica with the increase of Flints. Its Segregation and Aggregation in and around Sponges and other Organic Bodies. Origin of the Silica. What is the Analogy of the Chalk to the Globigerina-ooze of the Great Oceans? Researches of Carpenter, Gwyn Jeffreys, Wyville-Thomson. The Chalk Fauna not an Abyssal Fauna. Difference of Lithological Structure. Calcareous Precipitates. Exceptional Character of the Chalk-deposit.

Preliminary Physical Questions. The question of the origin of the Chalk-with-flints can hardly be dealt with without some knowledge of the condition of the Chalk-sea, its surroundings and its depth. On the last point the stratigraphical evidence shows that many changes of the sea-bed took place during the deposition of the Chalk, for there has been opportunely preserved at different levels on the original old rocky coast of the Ardennes an important series of the beaches of Cretaceous times. The southern slope of this mountain-range then formed the northern boundary of the Cretaceous sea; and fragmentary as the remains of the old beaches are, they nevertheless afford a valuable measure of the oscillations of the land, and indicate the levels at which the sea stood at successive stages in the Cretaceous period (see Table of Belgian beds, p. 300). They prove that its waters alternately advanced and retreated, and that, as the sea-bed emerged in one area, other areas became submerged and continued so to later periods.

With the many changes of level indicated by successive beach-lines, there were necessarily corresponding changes caused by variation in the currents, alteration in the sediments, in the depth, and by modifications in the fauna consequent thereon. We have proofs of such changes in slight variations of lithological structure (though this is not always the case), in the differences of the palæontological zones, and occasionally in the eroded surface of the strata. It is however not always easy, and sometimes it is almost impossible, to connect the shore-beaches with the deposits or zones of the deeper water. For example, at the end of the Turonian period, the sea-bed and its coast-line were raised x feet; and it would not be until after some subsequent submergence that the raised beach of that time would be again on the sea-level. It therefore might eventually be found on the same horizon with beds considerably younger, or it might remain on a higher and apparently more recent level.

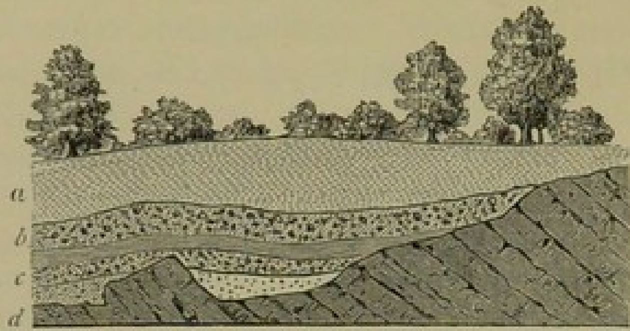

Fig. 165. *a. Nervian Marls. b, c, Old beaches* (Tourtia) *at the base of the Lower-Chalk. d. Devonian rocks; Bellignies, Belgium.*

Consequently, the exact correlation of the beach-lines and of the palæontological zones is in many cases yet uncertain even in the French and Belgian area, and the attempt made here to correlate them with strata in the English area must be taken only as approximative and tentative, and as needing further investigation. Still there can be no doubt of the intimate relation between the physical phases and the structural and palæontological conditions.

Oscillations of the Land. Some of the changes of level which took place during the deposition of the Cretaceous strata have been indicated in the last chapters. These changes gradually effected great alterations in the ancient physiography of the European area. Large tracts of Jurassic and Palæozoic strata which had long existed as dry lands now became transgressively covered; and as the sea encroached on the mountainous coasts, such as that of the Ardennes, it left the mark of its advance in successive beach-lines on the flanks of the submerged land.

In the Lower-Cretaceous series and in the lower part of the Upper-Cretaceous, it is easy to follow these changes owing to the marked difference in lithological character of the several stratigraphical zones; but in the Chalk, of which the composition is so homogeneous throughout, such changes long escaped notice. Late observations however, especially those made in the North of France and in Belgium, have shown, that during the deposition of the Chalk there were many such changes, as proved by the shingle-beds of the old shores and by the eroded surfaces of the Chalk at different stages. These changes are, as it might be supposed, accompanied by corresponding palæontological differences.

As already observed, there was at the close of the Jurassic period a very extensive emergence of new lands. A portion only of the Jurassic sea-bed remained under water, and there the Lower-Cretaceous strata succeeded without interruption; but the larger portion of the North-Western European area then emerged from beneath the sea. Two great rivers, draining this northern continent, formed the extensive deltas of the Weald and of Hanover, while further south was the open Neocomian sea. Another period of submergence succeeded, swamping not only much of the lands last emerged, but also extensive tracts of palæozoic rocks which had remained above the waters during Jurassic times. As the sea encroached north and west, it gradually silted up on the one side the deep bay existing amongst the palæozoic rocks of Bracquegnies, and on the other it spread similar sandy sediments over the Jurassic and Triassic beds of Dorset and Blackdown.

With the later submergence, which preceded the Chloritic Chalk, or the zone of *Ammonites Rothomagensis* (or *Am. laticlavius* of Barrois), the white calcareous sedimentation, which culminates in the White Chalk, commences. The beach-line of this period is probably that which now forms the Tourtia of Sassegnies[1],—a conglomerate containing pebbles of white quartz and of the underlying Devonian limestone, the surface of which is in places drilled by boring shells. This horizon may correspond with the zone of *Pecten asper* and with the coprolite- and pebble-bed at the base of the Chalk-marl in Cambridgeshire.

The well-known *Tourtia of Tournay* and *Montignies-sur-Roc* is likewise composed of pebbles of palæozoic rocks (quartzite, psammite, &c.) in a calcareous matrix, and has a large and special fauna. The corresponding deeper-water deposits of these shore-beds are seemingly the Chalk-marl with *Holaster subglobosus*, which passes further south, according to M. Barrois, into the 'Sands of Maine.' It is possible that the Totternhoe stone of Buckinghamshire is on this horizon.

On the northern boundary of the old Chalk-sea the base of the zone of *Belemnites plenus* becomes charged with grains of green sand, with some pebbles and rolled fossils. The change is well marked in the neighbourhood of Mons, where this bed constitutes the *Tourtia de Mons*. Its beach character is not so pronounced as that of the 'Tourtia de Tournay,' but it marks one of the most important changes in the old Chalk-sea,—fresh currents having been then established, which swept over and extensively

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[1] See Dr. Ch. Barrois's 'Mémoire sur le Terrain Crétacé des Ardennes,' Ann. Soc. Géol. du Nord, vol. v. p. 227.

denuded the older beds, the thickness of which varies considerably in consequence.

The zone of *Inoceramus labiatus* in Kent and in the cliffs of Cape Blanc-Nez, consists of a nodular Chalk-without-flints about 60 to 80 feet thick. As it ranges into Belgium it becomes more argillaceous (*Fortes-toises* and *Dièves*), and contains in its upper greenish marls large blocks of grey and banded flints (*verts à têtes de chat*): in places this zone swells out to a thickness of 300 to 400 feet. Further eastward, it passes into a clay so pure that it is worked for tiles, and southward into a chalk-marl. The Belgian facies represents the shallow-water conditions, and the nodular chalk the deeper-sea conditions, but these have not yet been identified with any well-defined beach. The Melbourne rock may belong to this zone.

One of the most decided breaks in the Chalk is that which exists between the Turonian and Senonian stages, or at the base of the zone of *Micraster cor-testudinarium*. Here again there is no well-defined beach-line, but it is found that over wide districts the underlying beds of the Lower Chalk have been broken up, the fragments rolled, rendered phosphatic, and in some places, as near Lille, covered with serpulæ and oysters: while, in the neighbourhood of Amiens, the surface of the underlying zone is largely eroded and pierced by boring molluscs. Here, therefore, is an instance of a temporary rise of the bed of the Chalk-sea, but without interruption in the continuity of chalk deposition which was maintained to the end of the Senonian stage.

Near Lille and Lens this basement-bed of the Senonian consists of a hard chalk about 12 feet thick, called *Tun*[1], which is worked at Lézennes. At the base it is full of nodular phosphatic concretions, with grains of glauconite. This form of hard chalk is found at various other places in the north of France, and corresponds exactly with our *Chalk-rock*, which forms so well-marked an horizon between the Chalk-with-flints and the Chalk-without-flints round parts of the London Basin. Here, as in France, are rolled fragments of chalk commonly coated with glauconite, and containing small proportions of phosphoric acid, possibly derived from masses of decaying animal matter.

The zone of *Micraster cor-testudinarium* is sometimes separated from the overlying zone of *Micraster cor-anguinum* by a band of broken and rolled fossils, but no beach-line is known. In the Paris Basin, carbonate of magnesia is occasionally present in some of the beds of this zone—sometimes in the proportion of as much as 35 per cent.

At the end of the Senonian period, the whole of the Chalk-sea underwent a rise accompanied by great erosion of the White Chalk—leading to

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[1] This is identical with the Chalk-rock above Wantage.

the emergence of some portions, and rendering other parts shallow. The Mons area still remained under water, and it was there that the remarkable bed of brown chalk, rich in phosphate of lime, was then deposited[1] (*ante*, p. 301). Another break, accompanied by great erosion of the surface, inaugurated the Danian or Maëstrichtian stage: a beach-line of that period forms the pebble-bed of Malogne. All the English and the larger part of the Paris-Basin area were now raised above the sea-level, while the cretaceous seas of Mons and Maëstricht alone continued to cover part of Belgium and Holland, and extended to Denmark and the Baltic.

Similar changes took place in the central and eastern European area. In Russia the White-Chalk sea encroached over a Jurassic land and reached the base of the chain of Devonian rocks, against which it stopped. Space will not allow us to enter into fuller details.

Origin of the Chalk. The profusion of microscopic forms of life in the White Chalk was pointed out half a century ago by Lonsdale. He showed that the piece of chalk which he examined consisted largely of Microzoa, such as Polyzoa, Ostracoda, and Foraminifera[2]. Ehrenberg further demonstrated that even the impalpable residue consisted really of still smaller Microzoa only visible under the higher powers of the microscope. According to Ehrenberg, about half the mass of the Chalk of the North of Europe is composed of organic remains, and, further south, he found the proportion larger[3]. Sorby states that he found some White Chalk to consist of 90 per cent. of Globigerina. Subsequent observers have, to a great extent, confirmed these conclusions with respect to the organic origin of a large portion of the White Chalk. Among the Foraminifera have been recognised many species of *Nodosaria*, *Cristellaria*, *Rotalia*, *Textularia*, *Globigerina*, &c. (Fig. 151, p. 290); and among the Polyzoa, species of *Idmonea*, *Ceriopora*, *Retepora*, and others (Fig. 157, p. 294). The minuter forms consist of *Coccoliths* and *Rhabdoliths*, with rare *Radiolaria* and *Diatoms*.

But, while the fact that the White Chalk is in great part (or in some portions) almost entirely of organic origin is unquestionable, the conclusion which has been drawn from it—that the whole of the chalk strata (as well as many other marls and limestones) are of like origin—is scarcely warranted. The primary object in view by the observers in such investigations having been to discover and eliminate the various organisms, the inorganic residue has consequently rarely been mentioned, or its proportion given. Ehrenberg incidentally remarked on the crystalline and inorganic

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[1] See M. Cornet's paper 'On the Phosphatic Beds of Mons' in Quart. Journ. Geol. Soc., vol. xlii. p. 325.

[2] See 'Catal. Foram. British Museum,' by Prof. Rupert Jones, p. 13.

[3] See also Mantell's 'Medals of Creation,' 2nd edit., p. 353.

character of some portions of the rock under examination; and Dr. Mantell observed [1] that, although it is easy to demonstrate the abundance of Foraminifera etc. in some masses of chalk, yet in many of the strata it is scarcely possible to detect any well-defined specimens, and that there is often a large proportion of atoms without traces of structure. There are also numerous instances in which it is stated generally, especially with reference to the lower divisions of the Chalk, that it contains no microscopic organisms; but a question may of course arise with respect to these observations as to whether they apply merely to Foraminifera or to the minuter Microzoa, and whether the power of the glasses used were sufficient to detect the more minute forms.

Sorby informs us that aragonite shells and corals may decompose in water into particles having so little relation to the organic structure that all proof of their origin might be lost, and that their form may not differ from that of any other kind of calcareous mud-granules, as, for example, those derived from the wearing down of older limestones, or those chemically deposited in an amorphous state; but I doubt whether we could ever get, by mere decay, a fine calcareous mud derived from calcite shells of peculiar crystalline texture, as *Pinna*, *Ostrea*, and Brachiopods, or from Encrinites. In the Chalk, as a rule, the more or less unbroken Foraminifera constitute only a part of the whole rock. The Globigerina are generally unbroken; but single detached cells of some other genera are of more frequent occurrence. Coccoliths also abound; but, on the whole, the larger calcareous organisms form the greater part of the rock. Amongst the most characteristic and abundant fragments are the detached needle-like prisms of the shell of *Inoceramus*. It is, however, not so much in its organic constituents as in its peculiar mineral condition that Chalk differs materially from most calcareous deposits. Mr. Sorby concludes that, although in such rocks as the Chalk 'we may often reasonably *infer* that the greater if not the whole was derived "from decayed and worn-down calcareous organisms," it is impossible to prove, from the structure of the rock, whether some, or how much, was derived from limestones of earlier date, or was deposited chemically, as some certainly must have been [2].'

The question, therefore, of the organic or inorganic origin of the amorphous portion of the Chalk remains open, and will have to be determined upon the evidence of further chemical analysis, as well as that of microscopic structure.

If we look to chemical analysis to see the proportion that the carbonate of lime, whether of organic or inorganic origin, bears to the

[1] 'Microscopical Examination of the Chalk,' etc., Ann. and Mag. Nat. Hist. for August 1845, and *op. cit.*, p. 354.

[2] 'Quart. Journ. Geol. Soc. Ann. Address for 1879,' pp. 71, 78, 92.

other materials of the Chalk, we find that there is a gradual increase of this constituent from the lower to the higher beds. (See Table, p. 322.)

Commencing with strata in which it is present only in the proportion of about six to twelve per cent., it increases rapidly to fifty or sixty per cent., then gradually to eighty, ninety, and ultimately, in the White Chalk-with-flints, to ninety-eight and even ninety-nine per cent. The residue consists in greater part of silica and argillaceous matter. With the increase of the carbonate of lime, there is an increase in the calcareous organisms. But it by no means follows that all the carbonate of lime from the base of the Chalk, where the rock is so impure, to the top, where almost all foreign matter (silica excepted) is absent, is of organic origin. It can hardly be supposed that the carbonate of lime of the lower calcareo-argillaceous beds, any more than that the calcareous matter of the lower calcareous sandstones, had that origin.

Nor must it be overlooked, that in the analyses of the White Chalk we are really only dealing with one portion of the rock; and that another, smaller, portion of the mass is equally an integral part of the total, although now separated out and constituting an independent substance.

Whether the silica of the flints be due, as suggested by Ehrenberg, to the segregation of the silex from diatoms and spicula, and their aggregation around organic centres; or whether it existed originally in the form of an amorphous chemical precipitate, as a constituent part of the chalk-ooze, from which it became separated by a process of segregation during solidification, it equally was dispersed through, and formed part of, the original calcareous mass; and the quantity in which it was present is easily determined by ascertaining the proportion which the flints now bear to the chalk. If we take, for example, as a mean in the chalk-with-flints a thickness of two to three feet for the beds of chalk, and of one to three inches for the layers of flint, and divide this by one half to allow for the interspaces due to their form, it gives a proportion of about 4 to 6 per cent., as the original proportion of silica in the Chalk-with-flints.

The analysis of the White Chalk over a wide area, makes it evident that little or no detrital matter found its way into those parts of the Chalk Sea when and where it was deposited in a pure state. Such, however, was not the original conditions of that sea, for the lower divisions of the Chalk series, in the same area, contain much detrital sand and clay, and in places fragments of slate and other rocks. We have seen that there are old shore-lines of the Chalk-marl, and of the zone of *Belemnites plenus*, on the slopes of the Ardennes, which consist of a shingle composed of the palæozoic rocks of that old mountain-chain, so that it is clear that at the Cenomanian and Turonian periods the Cretaceous sea had a much more restricted area than at the later Senonian period, when it spread over the Palæozoic rocks to the north, as far as Denmark and Sweden.

In consequence of the proximity of the old coast-lines[1] during the Cenomanian period, the strata in the Anglo-French basin were composed more largely of sands and clays derived from this adjacent land. As this land subsided, the shore-lines receded inland, and the central sea-area became deeper, and more beyond the range of drifted sedimentary matter, and then the sediments deposited became restricted mainly to the débris of the dead shells and skeletons of the microscopic organisms which inhabited those open seas. There are, however, portions of the strata in which these organisms are either rare or absent, and where the Chalk is largely composed of impalpable amorphous matter, and this may either be derived from disintegrated organisms, or from older calcareous strata, or it may be a chemical precipitate thrown down under special and peculiar conditions prevailing at the time. To this we shall again refer presently.

Origin of Flints. This brings us to the consideration of the origin of the flints, a subject which has long engaged the attention of geologists. Many had, at an early period, noticed the probable relation of the chalk-flints to some form of sponges; but it was reserved for Dr. Bowerbank[2] to prove, by an elaborate microscopical examination of the structure and form of flints and of sponge-tissue and spicula, the intimate connection between the two, and to show to how great an extent the flint nodules of the Chalk retain traces of the original sponges, in and around which he supposed the siliceous matter to have segregated. Dr. Bowerbank even supposed the masses of tabular flints, and the flint filling the shells of Echinodermata and Mollusca, to be of sponge origin. The source of the silica he considered to have been the silica brought down in solution by rivers or furnished by springs.

Other geologists have suggested that the silica carried down in solution by rivers was first elaborated by the marine siliceous Diatomaceæ, Radiolaria, and by Sponges; and that then the silica of these various organisms, by some process of segregation and fluxion, collected round various organic bodies, ran together into nodules, or filled shrinkage-cracks[3].

Another suggestion is—that the aggregations of silica present in Chalk and other lime-rocks are due to the replacement of amorphous carbonate of lime by silica as a pseudomorph, as in the instance of flint after polyzoan

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[1] See also papers by the late Mr. R. A. C. Godwin-Austen in Quart. Journ. Geol. Soc.,' vol. xii. p. 68, and vol. xvi. p. 329.

[2] 'Trans. Geol. Soc.,' 2nd ser., vol. vi.

[3] Lyell, 'Student's Elements,' edit. 1871, p. 264; and 'Principles of Geology,' edit. 1872, vol. i. p. 216; and Bischof's 'Chemical and Physical Geology,' chaps. ix. and xlii.

chalk, corals, oolite, etc. The infinite number of spicules and foraminifera holding the same relative position in the pseudomorph as in the original mud or ooze is adduced in support of this view[1]. It has also been suggested that the silica of flints is a pseudomorph after carbon.

Another explanation has been proposed by Dr. Wallich[2], based on the supposed wide distribution of a sponge-protoplasm (like the 'Bathybius' of Huxley) over those areas of the abyssal ocean that are occupied by the calcareous mud of the Globigerina-ooze. Dr. Wallich considers that nearly the whole of the carbonate of lime of the Chalk has been derived partly from Foraminifera and other organisms that have lived on the bottom, and partly from such as have subsided to the bottom after death; and that the silica of the flints has been derived mainly from the deep-sea sponges with their environment of protoplasmic matter. The flints are supposed to be just as much of organic origin as the Chalk itself; and it is surmised that the stratification of the flint results from the circumstance that all sessile Protozoan life is confined to the superficial layer of the muddy deposits. The reader should, however, consult the several original papers here referred to, where the subject is discussed at length.

There is another view, arising from considerations connected with the chemical composition of the Cretaceous and some other strata, which may be suggested. Certain rocks, first noticed by M. Sauvage in the Oxfordian strata of the Ardennes, contain a large proportion of soluble silica, apart from the silica present in the form of sand or detrital quartz. This substance has since been found abundantly in several of the lower members of the Upper-Cretaceous series, both in England and on the Continent, where it forms a very light porous rock, known by the name of *Gaize* (Vol. I, p. 31). Silica in this state forms an impalpable white powder of low specific gravity, and is readily acted upon by water holding carbonic acid or weak alkalies in solution[3].

Professor Way found 24 per cent. of soluble silica in the Upper Gault of Farnham, 46 per cent. in the Firestone, and as much as 72 per cent. in some other beds of the Upper Greensand. In the Chalk-marl it is reduced to 31 per cent., and then falls off in the Chalk-without-flints to two and three per cent., disappearing altogether in the upper part of the Chalk-with-flints. In the Meule de Bracquegnies it exists, according to MM. Cornet and Briart, in the proportion of 54 per cent.; and M. Savoye has detected it in all the lower divisions of the Chalk in the North of France. Few other analyses have been made with

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[1] 'On the Forms of Silica Geologically Considered,' by Prof. Rupert Jones, Proc. Geol. Assoc., vol. iv. No. 7: Bischof, vol. i. p. 199; vol. ii. pp. 479, 489.

[2] 'Quart. Journ. Geol. Soc.' for Feb. 1880.

[3] This form of Silica is soluble in nitric acid, and in boiling alkalies, whereas ordinary quartzose sand can only be dissolved by fusion with caustic alkalies.

the object of determining the presence of soluble silica, which is no doubt usually merged in descriptive analyses under the general head of 'silica,' and so passes unnoticed.

The following Table, which is compiled from the papers of Professor Way[1] and M. Savoye[2], shows the large percentage of soluble silica in the Lower-Cretaceous beds, together with the gradual decrease of the insoluble detrital materials, and the increasing proportion of carbonate of lime as we ascend from the Chloritic Chalk to the Chalk-with-flints.

Strata.	Locality.	Insoluble in acids. — Fine sand, clay, etc.	Soluble in Acids or in Caustic Potash. Carb. of Lime.	Carb. of Magnesia.	Phosphoric Acid.	Alkaline Carbonates.	Iron Oxides.	Soluble Silica.	Total. Soluble.
White Chalk-with-flints.	Shoreham.	1·52	98·40	0·48	...	...	...	...	98·48
	Farnham.	0·66	98·20	0·20	0·08	0·30	0·74	...	99·34
	St. Omer.	1·13	97·45	0·41	0·01	...	0·40	0·10	98·87
Lower Chalk-without-flints.	Obas	2·04	95·00	0·60	0·70	0·42	0·55	trace	92·74
	Farnham.	7·26	84·00	2·80	0·05	3·20	1·94	2·11	97·96
	St. Omer.	20·62	76·22	0·28	0·01	...	1·10	0·99	79·38
Chalk-marl.	Farnham.	21·35	68·50	0·70	0·21	4·30	2·31	2·16	78·65
	Lille	36·73	58·64	0·83	0·11	...	0·60	0·58	63·27
Chloritic Chalk or Marl.	Cambray.	40·48	56·42	0·21	0·20	...	2·20	0·52	59·44
	Farnham.	31·18	6·00	1·00	3·76	4·41	16·91	31·88	64·61*a*
Firestone.	Farnham.	38·75	0·26	0·07	...	1·22	9·27	46·28	57·10*b*
Gault (upper).	Farnham.	62·68	0·75	0·26	trace.	0·51	5·50	24·80	31·80*c*

Loss and combined water—*a*, 4·21; *b*, 1·60; *c*, 5·49.

The soluble silica, which is present in the strata as an amorphous impalpable powder, is a chemical precipitate. I imagine that during the sedimentation of the Upper Gault, Greensand, and Lower Chalk, silica, held in solution by alkalies or carbonic acid, was introduced in exceptional quantities into the Cretaceous seas by rivers and springs, and that it there underwent decomposition in presence of some of the sea-salts. It would further appear, that under certain conditions, such as the presence of sponge substance and siliceous spicula, the silica in its nascent and colloidal state was segregated, sometimes merely agglutinating the sand round the fossils, as with the Sponges of the Warminster beds; at others, forming the cherty layers or ragstone of the Folkestone beds; and, where in greater excess,

[1] 'Journ. Royal Agric. Soc.,' vol. xii. p. 544.

[2] 'Mém. Soc. Sci. Agric. et des Arts de Lille,' 3e sér., vol. viii. p. 425. It is probable that the French analyses do not give the full proportion of soluble silica or correct comparative results, as M. Savoye employed hot dilute nitric acid, whereas Professor Way employed a solution of caustic potash.

running together with the flint spicules and the quartzose sand, and forming the seams of chert in the Upper and Lower Greensands. Elsewhere in beds of this age, the nascent soluble silica has been, in the absence of Sponges, attracted by the organic matter of the Mollusca, which it has replaced. This has happened also frequently with the calcareous tests, as in the instance of the shells in the sands of Blackdown, Bracquegnies, and others.

In the lower beds of the Chalk, soluble silica is still present to the extent of 20 to 30 per cent., but it rapidly decreases, or rather ceases to exist, in that particular amorphous form met with in the higher beds. At the time the former were being deposited a portion of the silica was abstracted, while yet in solution, by the living organisms of Sponges, Radiolaria, and Diatoms; while another portion, thrown down as a chemical precipitate in the calcareous ooze, gradually replaced the decaying organic matter, or segregated around the siliceous spicula and other organisms, and so formed the layers and nodules of flint which then commence to appear. The restriction, however, of the flints to the upper part of the White Chalk in the South of England is a local phenomenon. They occur in lower parts of the Chalk in Yorkshire and on the Continent. Flints, for example, are distributed irregularly both in the Cenomanian and in the Turonian strata of France; while in Belgium, large siliceous masses (Têtes de Chat) and huge blocks of grey flint abound in strata the equivalent of our Chalk-without-flints and Chalk-marl.

But in this country it is only at the base of the Senonian or the White Chalk that flints set in in great abundance, and it is at this level, precisely where the attractive affinity of the sponge and other organic matter to which they are due has thus fully come into play, that amorphous soluble silica in the rock itself almost entirely disappears, and the silica is represented only by the layers of flint, which are present in the proportion, before mentioned, of about 4 to 6 per cent. of the whole mass.

I think, therefore, there is reason to conclude it is to the presence of silica in the peculiar condition known as soluble silica that the formation of flints is due. Silica, in its colloidal state, has strong affinity not only with other forms of silex, but also with any gelatinous substances[1]. The siliceous spicula of the Sponges furnished one centre of attraction, and the sarcode or substance of the Sponge, which is a gelatinous body agreeing closely in chemical composition with ordinary gelatine, furnished another. In presence of such bodies, the soluble or colloidal silica, dispersed through the soft chalk-mud, slowly segregated from out of the surrounding pulpy mass, and gradually replaced part, or the whole, of the organic matter as it decayed away. Nor has it stopped there: owing to the affinity of the particles of colloidal silica amongst themselves, the segregation has not

[1] Graham, 'On the Properties of Silicic Acid,' etc., Chemical Researches, pp. 618–625.

ceased with the replacement of the organic body, but has continued so long as any portion of silica remained in the surrounding soft matrix,—whence the frequent excess of flint beyond the interior or body of the shells, echinoderms, etc., and whence also the irregular shape arising from this overgrowth of the flint nodules.

But although the Sponges have afforded the stronger affinity-centres, the substance of many other organisms has also furnished other, although apparently less attractive, centres. In this way, the interior of the tests of echinoderms and of the shells of molluscs are often filled with flint—replacing the animal matter they contained, and continuing, as with the Sponges, often to overflow. Even a small proportion of organic matter, such as is present in shells, corals, some lime-stones and oolites, may give rise to this elective affinity and produce silicification and pseudomorphism.

With respect to the origin of the silica in these particular strata, the quantity carried down ordinarily by rivers will hardly account for it, as the amount of silica in solution in river-waters does not exceed 0·004 to 0·02 gramme per litre. There must be some cause to account for its excess in certain geological periods, for its profusion and gradual diminution during the Cretaceous period, as also a reason for its absence at other periods. Either the rivers were fed by numerous such springs as those of Vichy, in which silica is in the proportion of 0·113 gr. per litre, and of Aix-la-Chapelle, where it amounts to 0·332 gramme (both derived from old or crystalline strata); or else there may have been adjacent continental tracts with drainage-areas of much decomposed felspathic rocks. Such sources of supply may have existed, amongst others, in the old range of the Ardennes, which formed the northern boundary of the Cenomanian and Turonian seas, or in some adjacent granitic area, or in the crystalline rocks of the Scandinavian range, up to the foot of which the Senonian sea finally advanced[1].

What is the Analogy of the Chalk to the Globigerina Ooze? It had been long suggested[2] that the Chalk was in all probability a deposit formed in a deep sea far from land; but at the time this suggestion was first made scarcely anything was known of the deep-sea deposits beyond the 200 fathoms line. The novel and interesting researches of the late Dr. Carpenter and Dr. Gwyn Jeffreys in the 'Lightning' and 'Porcupine,' and of Sir Wyville Thomson and other naturalists in the 'Challenger,' threw a flood of light on this unexplored field, and gave opportunities of comparison before wanting.

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[1] The presence of silica in the waters of both these areas indicates the possibility of its presence there in larger quantities at the earlier geological periods, when the springs were newer and in all probability stronger.

[2] Mantell, 'Wonders of Geology,' p. 324, 1857.

It was anticipated at first that there had been discovered in the abyssal depths of the great oceans a modern deposit not merely analogous to but homologous with the Chalk. The Globigerina-ooze, which extends in the Atlantic from depths of 800 to 2600 fathoms, is, like the Chalk, a white or light-coloured earth, consisting largely of calcareous Foraminifera, which, with few exceptions, are of the same genera,—such as Globigerina, Nodosaria, Dentalina, Cristellaria, etc. (Fig. 151, p. 290), as those which occur in that Formation; while out of 110 living oceanic species, Professor Rupert Jones has recognised 19 species [1] occurring fossil in the Chalk. Then again, the abundance of siliceous Lithistid and Hexactinellid sponges, attached by fine rootlets to the surface of the ooze, presents another point of analogy; inasmuch as the Atlantic *Holtenia*, *Sympagella*, etc. represent very closely the Cretaceous Siphonias and Ventriculites, though they belong to a distinct subsection of the Hyalospongia. Further, Starfishes, Crinoids, and Echinoids of Cretaceous genera, as for example *Salenia*, or of forms closely allied to such well-known genera as *Micraster* and *Ananchytes*, were found to be common at those depths. Amongst the Fishes, a Beryx was found, a genus of which there are four species in the White Chalk. These and a few other similar facts form marked and striking points of resemblance, and thus led to the suggestion that the Globigerina-ooze was possibly a deposit which had been going on from the Cretaceous period to the present time, and that it was in fact a continuation of the Chalk Formation, or a modern chalk deposit.

These views are of high interest, but they have not been confirmed by subsequent research, nor are the conclusions in accordance with other and essential geological and palæontological conditions which obtain in the Chalk. By far the greater number of forms discovered on the 'Challenger' Expedition are new to science, and present only distant analogies to extinct forms. The Echinoderms and Molluscs of the present abysses are mostly of small size, and Brachiopods and Cephalopods, so abundant in the Chalk, are very scarce in the existing oceanic deposits [2]. Dr. Gwyn Jeffreys has shown that the greater number of the Mollusca found in these depths are dwarfed forms of species living in the shallower waters of the North Atlantic and Mediterranean, and that they have their nearest allies in Pliocene or Upper-Miocene forms of Italy and the Crag beds of this country. His conclusion was that the Chalk Mollusca are of such species as lived in comparatively shallow waters.

One coral (*Fungia symmetrica*) was obtained by the 'Challenger' from the great depth of 2750 fathoms; but, with that exception, none exceeded the depth of 1500 fathoms; while of the total forty-two genera

[1] Including *Glandulina lævigata*, *Nodosaria radicula*, *Dentalina communis*, *Cristellaria rotulata*, *Polymorphina compressa*, etc.

[2] For a brief account of the Oceanic oozes see chap. viii. vol. i. of this work.

discovered, twenty-seven exist at depths of from 25 to 250 fathoms; and fifteen do not range beyond 500 fathoms. Of the forty-two genera, eight also are genera that are found in the Chalk. They include *Caryophyllia* which ranges from 50 to 1500 fathoms; three genera ranging from 50 to 1000 fathoms; while the other four do not go beyond the depth of 250 fathoms [1].

Fishes, like some corals, have a wide range in depth, but the families and genera which are common to the Chalk and to the recent seas have definite and moderate limits. *Beryx* was found down to 345 fathoms [2]. Of the Sharks, which form the great bulk of the Chalk fishes, Dr. Günther says that few descend to a considerable depth, probably not exceeding 500 fathoms; while amongst Rays, only one has been caught in more than 100 fathoms.

Professor Rupert Jones informs me that the Foraminifera are, as a rule, such as live at depths of about 100 fathoms, or a little more.

Sir Wyville Thomson [3] sums up with respect to the abyssal fauna—that, although all the principal marine invertebrate groups are represented, the relative proportion in which they occur is peculiar. Thus, Mollusca, in all their classes, Brachyurous Crustacea, and Annelida, are on the whole scarce; while Echinoderms and Sponges greatly preponderate. He further considers that the distribution of the abyssal fauna itself is dependent on conditions of temperature; and that in its general character it resembles that of the shallower waters of high northern and low southern latitudes [4].

Although existing Sponges have wide bathymetrical limits, still, on the whole, they afford good data as to the depth of the sea in which the Chalk Sponges lived. The Tetractinellidæ, formerly regarded as inhabiting rather shallow waters, have been shown by the 'Challenger' Expedition to extend to depths previously thought to be exclusively inhabited by Lithistidæ and Hexactinellidæ; a species of Pachastrella with spicules closely resembling some found in the Chalk was dredged in the Atlantic at a depth of 292 fathoms. Lithistid sponges, nearly allied to Rhacodiscula, occurred at depths varying between 120 and 270 fathoms, and the Hexactinellidæ were found to be most abundant in depths of 300 to 1000 fathoms [5].

On this evidence alone we might conclude that the depth of the sea in which the Chalk was deposited did not exceed 2000 to 3000 feet; but the geological evidence before given, derived from the erosive action of tides and currents, from beach-lines and littoral mollusca, would point even to

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[1] Professor Moseley's 'Preliminary Report, Proc. Roy. Soc.,' vol. xxiv. p. 566, 1876; and vol. i. p. 126 of this work.

[2] 'The Study of Fishes,' pp. 307, 315, 336.

[3] 'Voyage of the Challenger,' vol. ii. p. 352.

[4] *Op. cit.*, vol. ii. p. 299.

[5] Dr. George Hinde's 'Fossil Sponge Spicules from the Upper Chalk,' p. 77.

lesser depths—of possibly not more than 1000 to 2000 feet. The one difficulty is the remarkable rarity of drifted materials in the White Chalk, and its evident largely organic origin, characters which would seem to belong to a formation deposited in still and rather deep waters far from land.

Notwithstanding its pelagic abyssal origin, the Globigerina-ooze is far from possessing the purity of the White Chalk. While the latter consists of from 96 to 98 per cent. of carbonate of lime, or, taking into account the silica that has gone to form the flint, of from 92 to 94 per cent., in none of the analyses of the ooze does the calcareous matter exceed 81 per cent., and in a large number of instances it is between 50 (in one case only 44) to 70 per cent., or less even than in the Grey Chalk to which Sir Wyville Thomson likens it[1]. The Globigerina-ooze also contains generally small particles of quartz, mica, magnetite, felspar, augite, and pumice, but as a rule nothing of the sort is found in the White Chalk, and little (in few places only) in the Grey Chalk; and of the manganese concretions so common in the ooze, none.

Neither great depth of water, nor great distance from land, therefore ensures at present that purity of composition which forms so exceptional a character in the Chalk. Its peculiar freedom from such impurities as occur in the Globigerina-ooze must be due to other causes: it may possibly be owing to the chalk-sea having been a nearly enclosed sea, with few currents, like the Mediterranean or the Black Sea; or it may have been a sea of an archipelago, the islands having no large rivers, while the coast (the Ardennes) consisted of hard and crystalline rocks, so that the amount of detritus carried down into the sea was small (as now in the Red Sea). There would, however, appear to have been something beyond this. Deep-sea deposits, like the Globigerina-ooze, are supposed to be of very slow growth, whereas there is some reason to suppose that the Chalk was not of this slow growth; for it is difficult to conceive that the Fishes of the Chalk, when, as not unfrequently happens, their scales and even their bones are nearly entire and undisturbed (and the body but little crushed), could have been preserved in that state otherwise than by a rapid entombment of the decaying body, which under other circumstances must have fallen to pieces; nor is it easy to account for the state of preservation of the Crinoids with their arms but little disturbed, and the Cidaridæ with their spines in position, if they had been left exposed for the long period of time assigned to the growth of such ooze. These and other concurring conditions induce me to believe that, in addition to the accumulation of organic calcareous débris, there was at the same time a considerable chemical precipitate of carbonate of lime taking place in the Chalk Sea.

Admitting the permanence of law, it is not possible to admit, if we adopt the hypothesis of an originally molten globe, as most geologists now

[1] See vol. i. p. 123.

do, the permanence of physical conditions ; and with the necessary changes in those conditions in the course of time, combinations special to each successive phase in the earth's history must have resulted. The same causes may have come into operation again and again ; but, if their relations were different at different times, the effects would present corresponding variations. With increasing rigidity of the crust with age, the folds on the earth's surface have become both deeper and more permanent, and it may be a question whether in the Cretaceous Period the abyssal depths were equal to those of the present day, although it is more than probable that some of the present great depressions then existed in a rudimentary state. Nevertheless, as a very large portion of Europe and of North America, together with parts of Asia and Africa, were submerged during the Cretaceous period, it is certain that some corresponding differences must have existed in the distribution of the great ocean-basins. The existing depressions of the Atlantic run north and south, whereas some of the great Cretaceous basins ran east and west, or were nearly at right angles to the existing configuration. (See Map of the World in Vol. I.)

If portions of the original cretaceous basins still exist, it can only be at the points of intersection of the old with the existing great basins. In other respects the hydrographical basins of the two periods were independent and distinct ; and consequently the tides and great oceanic currents were different. Is it not possible, with the extensive alterations in the distribution of land and water effected at the close of the Cretaceous period, or at the opening of the Tertiary period—such as the deepening of the North Atlantic—that some of the powerful Arctic currents, which now sweep the bed of the Atlantic, may have originated ; and that these great bodies of cold water, which have at their base a temperature only just above the freezing point, and which would have affected the temperature not only of the sea but of the land, may have been in some measure instrumental in the striking change in the flora and fauna, including the destruction of the great marine reptiles of the Mesozoic Period, which then took place.

In no period of the past do we find deposits exactly of the character of the abyssal 'Red Clay' and 'Globigerina-ooze,' nor do we meet at the present day with the exact homologue of the Chalk. The conditions under which it was deposited were peculiar and special ; and, though it presents many points of analogy to the calcareous ooze, there are none of identity, and the Chalk stands alone amongst the British strata, in its peculiar structure and origin. It is for these reasons that I have taken the opportunity of making the foregoing remarks, not because the Chalk forms an exception to the general rule of constant change, but because its features are so clear and so well marked that it serves better than most other deposits to illustrate this law of unceasing variation.

CHAPTER XXI.

REVIEW OF THE MESOZOIC PERIOD.

ORDERS OF LIFE EXISTING DURING THE MESOZOIC PERIOD. RANGE IN TIME OF THE PRINCIPAL ORDERS AND FAMILIES. THE MORE COMMON AND CHARACTERISTIC GENERA BELONGING TO THE SEVERAL MESOZOIC FORMATIONS. NUMERICAL TABLE OF SPECIES.

THIS Period opens, in the European area, with an impoverished fauna and flora, a consequence, in all probability, of the extensive modifications of the surface which took place at the close of the Palæozoic period and led either to the partial destruction or to the temporary migration of life from the districts so affected. Whereas the fauna in Carboniferous times, in the English area, numbered 1988 species, it dwindled in the Permian, after the disturbances of that period, to 203 species, and in the Trias to only 187; but in the Lias it again increased to 1804 species (see Tables VII and VIII, p. 152, and p. 333). All the species and a large number of the genera and families become extinct at the close of the Palæozoic period.

In the Mesozoic period a large number of new genera, families, and orders make their appearance; and all the species are new. There is no gradual change, as from the Silurian to the Devonian, or from the latter to the Carboniferous; the change is sudden and trenchant. The break both stratigraphically and palæontologically is equally important. It is certain, however, that there was no universal break in the continuity of deposition, or of life. The continuity was uninterrupted in other parts of the world (see Tables, pp. 6–18). Following the plan we have adopted with the Palæozoic series, the lists below indicate the general characters of the life on the Earth during the Mesozoic period in the European area.

Life of the Mesozoic period. The following is the order of the first appearance of the principal classes:—

Mammals { **Non-Placental.** Confined to small Marsupials, which first appear towards the close of the Triassic period. **Placental.** None.

Birds . . . . There is no well-established record of Birds until late Jurassic times. These Birds differ from those of more recent times in having had teeth like those of Reptiles and Fishes, and a tail formed by the prolongation of the vertebræ like the tail of Reptiles and Mammals. Only known at Solenhofen.

Reptiles . . . All the orders of living Reptiles, *with the exception of the Ophidians*, are represented, together with the extinct Enaliosauria (*sea-Saurians*); Dinosauria (*land-Saurians*); Pterosauria (*flying-Saurians*); Anomodontia (*abnormal-toothed reptiles*).

Amphibians	The Labyrinthodontia continue to exist only during the early part of this period. The Anoura (*tail-less amphibians*) do not yet appear.
Fishes	The Ganoidei and Elasmobranchii continue to abound throughout this period. Teleostean fishes did not exist in Jurassic times; but they appear towards the close of the Cretaceous epoch.
Molluscs	The Cephalopods are the predominant class. The Dibranchiate Cephalopods and the Siphonostomata or zoophagous Gasteropods now first appear. Ammonites and Belemnites are amongst the characteristic forms peculiar to the Mesozoic period. The Monomyarian Bivalves are very abundant.
Brachiopods	Of the Palæozoic Brachiopods, only Terebratula, Rhynchonella, Lingula, and Crania survive. The first two are extremely abundant. The genera Thecidium and Waldheimia first appear.
Polyzoans	The Mesozoic Polyzoa are extremely numerous. All the existing families are represented, especially genera of Escharidæ and Diastoporidæ in the Jurassic, and of Idmoneidæ and Cerioporidæ in the Cretaceous period.
Insects	Beetles, Grasshoppers, and Cockroaches, together with Dragon-flies and May-flies, are not uncommon in several of the Mesozoic formations from the Lias upwards.
Myriapods and **Arachnids**	Centipedes and Spiders are generally sparingly represented, but are more common in the Upper Jurassic of Solenhofen.
Crustaceans	In place of the extinct Palæozoic Trilobites and Eurypterids, genera allied to existing families of Lobsters, Crabs, Shrimps, etc., now appear in considerable numbers. Minute Entomostraca abound in the various Jurassic clays, in the Purbeck and Wealden Formations, and in the Gault and Chalk.
Annelids	Serpulæ and Vermiculariæ are the predominating and common genera throughout.
Echinoderms	Echinoidea and Asteroidea are extremely numerous and characteristic, both in the Jurassic and Cretaceous strata. Crinoids are less common, with the exception of Pentacrinites, which sometimes abound. The Ophiuridæ are chiefly Jurassic.
Cœlenterates	*Actinozoa.* Corals are extremely common in the Oolites, in which they often form banks of considerable extent. They belong to the same great groups as those existing in the present seas. *Spongidæ.* Sponges, sparsely distributed through the Jurassic strata of Britain, abound in the Neocomian and Cretaceous strata. On the Continent, however, they are equally common in some of the Jurassic Formations, of which they form, in places, a large part of the constituent strata.
Foraminifera	The Porcellanous, and one section of the Hyaline, Foraminifera are comparatively rare; while another section, including the Nodosarinæ and Globigerinidæ, together with numerous Arenacea, occur in profusion in many both of the Jurassic and Cretaceous Formations.
Plants	Ferns, Cycads, and Conifers are the predominant and almost only orders during the Jurassic period. An abundan tangiospermous flora, composed in greater part of existing genera, makes its appearance in the Cretaceous period.

Range in Time. The following is the order in geological sequence in which some of the principal orders and families of the animal kingdom appeared and died out during the Mesozoic period in Europe:—

Trias	*First appearance* of Waldheimia, Ammonites, Cidaridæ, Diademidæ; Dapedidæ; Enaliosaurians, Pterosaurians, Dinosaurians, and Placental Mammals (*Microlestes*). *Last appearance* of Labyrinthodonts, Goniatites, Orthoceratidæ, Conulariæ.
Lias	*First appearance* of Belemnites, Teuthidæ; true Sharks and Sturgeons; Teleosaurians. *Last appearance* of Spiriferidæ.
Lower Oolites	*First appearance* of Echinobrissidæ and Echinoconidæ; Chelonians; and Brachyurous Crustaceans.
Middle Oolites	*First appearance* of Sepiadæ.
Upper Oolites	*Last appearance* of Teleosaurians.
Neocomian	*First appearance* of Hippuritidæ, Spatangidæ, Terebratella, and Teleostean Fishes.
Upper Cretaceous	*First appearance* of Angiospermous Dicotyledons. *Last appearance* of Enaliosaurians, Pterosaurians, Dinosaurians; Ammonites, Belemnites; Rudistes; and Echinoconidæ.

The families and genera of the Invertebrata confined to Mesozoic strata are fewer in number than those restricted to the Palæozoic series, for though a large number of new genera make their appearance, the greater proportion, especially of the Mollusca, pass upwards into the Tertiary strata, and many survive to the present day. On the other hand, the Reptilia have more typical characters and a less prolonged range.

Mesozoic Genera. The following genera are in greater part peculiar to this period. Those which are figured in Plates IV to XII are marked by an asterisk. Others will be found among the woodcuts.

PLANTS.

Acrogens	Sagenopteris, Camptopteris, Tæniopteris, Lonchopteris, Thinnfeldia, Glossopteris, Goniopteris, Odontopteris.
Gymnosperms	*Cycads*: Pterophyllum, Otozamites, Zamites, Crossozamia, Yatesia, Fittonia, Bennettites, Palæozamia, Cycadites, Ctenis, Williamsonia, Beania, Mantellia. *Conifers*: Brachyphyllum, Taxodites, Peuce, Thuites, Araucarites, Abietites, Pinites, Voltzia, Albertia.
Angiospermous Dicotyledons	Credneria, Protophyllum, Dryophyllum, Camptonites, Alnites.

INVERTEBRATA.

Foraminifera	Parkeria, Cuneolina, Polyphragma.
Cœlenterata	*Actinozoa*: Isastræa, Thecosmilia, Montlivaltia, Stylina, Latimæandra, Thamnastræa, Rhabdophyllia, Cyathophora, Cyathocœnia, Trochosmilia, Similotrochus. *Spongidæ*: Siphonia, Peronella, Stellispongia, Raphidonema, Ventriculites, Verruculina, Camerospongia, Cephalites, Doryderma, Jerea, Hallirhoa, Corynella, Plocoscyphia.
Echinodermata	*Jurassic*: Clypeus*, Hemicidaris*, Acrosalenia*, Collyrites*, Pygurus*, Echinobrissus*, Pseudodiadema*, Hemipedina*, Holectypus*, Hyboclypus*, Pygaster*, Glypticus*, Stomechinus*, Cidaris. *Cretaceous*: Trematopygus*, Catopygus*, Salenia*, Holaster*, Discoidea*, Cyphosoma*, Echinocorys*, Peltaster*, Cardiaster*, Goniophorus*, Pyrina*, Echinoconus*, Micraster*, Glypticus*, Polycyphus*, Cidaris*, Apiocrinus, Extracrinus, Astropecten, Goniaster, Uraster, Ophioderma, Ophiolepis, Ophiurella.

CRUSTACEA.

Isopoda	Archæoniscus.
Macrurous Decapods .	Glyphea, Eryon.
Brachyurous ,,	Palæinachus, Palæocorystes.

MOLLUSCOIDEA.

Brachiopods . . .	Koninckia, Magas, Terebrirostra*, Megerlia, Zelania.

MOLLUSCA.

Lamellibranchs . .	Gervillia*, Pachyrisma*, Inoceramus*, Macrodon*, Gryphæa, Exogyra, Pteroperna*, Monotis, Myophora, Diceras, Hippurites*, Radiolites, Caprina, Gonomya*, Hippopodium, Gresslya*, Cardinia, Ceromya*, Myacites, Homomya, Hinnites*, Opis*, Tancredia*, Unicardium, Trichites, Trigonia (*survived in the Australian seas*).
Gasteropods . . .	Nerinæa*, Alaria*, Trochotoma*, Cylindrites*, Cinulia*, Pileolus*, Purpuroidea*, Amberlya*.
Cephalopods . . .	Ammonites*, Belemnites, Geoteuthis, Leptoteuthis, Beloteuthis, Turrilites, Baculites, Hamites, Ancyloceras, Ceratites (*only Triassic*), Crioceras, Scaphites.

VERTEBRATA.

FISHES.

Elasmobranchs . .	Ischyodus, Hybodus, Acrodus, Strophodus, Notidanus, Ptychodus, Chondrosteus.
Ganoids	Lepidotus, Dapedius, Amblypterus, Æchmodus, Tetragonolepis, Sauropsis, Mesodon, Eugnathus, Aspidorhynchus, Belonostomus, Caturus, Pycnodus, Leptolepis, Macropoma, Sphærodus, Gyrodus.
Teleosteans . . .	Berycopsis, Osmeroides, Euchodus, Pelecorapis, Stratodus, Syllæmus.

REPTILES.

Chelonians . . .	Enaliochelys.
Lacertilia . . .	Mososaurus, Telerpeton, Hyperodapedon, Rhynchosaurus, Placodus, Nuthetes, Echinodon, Raphiosaurus, Leiodon, Tylosaurus.
Crocodilia . . .	Teleosaurus, Steneosaurus, Stagonolepis, Belodon, Goniopholis, Diplosaurus.
Thecodonts . . .	Thecodontosaurus, Palæosaurus.
Enaliosaurians . .	Ichthyosaurus, Plesiosaurus, Pliosaurus, Amphisaurus, Bathygnathus.
Dicynodonts . . .	Dicynodon, Ptychognathus.
Pterosauria . . .	Pterodactylus, Rhamphorhynchus, Dimorphodon.
Dinosaurians . . .	Iguanodon, Megalosaurus, Cetiosaurus, Hylæosaurus, Hypsilophodon, Hadrosaurus, Campognathus, Chondropteosaurus.

BIRDS.

Saururæ. . .	Archæopteryx (*Solenhofen*).

MAMMALS.

Marsupials . . .	Microlestes, Amphitherium, Phascolotherium, Stereognathus, Plagiaulax, Triconodon, Spalacotherium.

Several of the most characteristic genera in the above list, peculiar to the Mesozoic series, are figured in Plates VI to IX. The typical forms peculiar to the Cretaceous formations are figured separately in Plates X to XII. As far as possible, the same classes are represented as in the Jurassic series. The numerical distribution of series is given in the following Table, which is compiled from the valuable lists (before referred to) of Mr. R. Etheridge, F.R.S.

TABLE VIII.—SHOWING THE NUMBER, CHARACTER, AND DISTRIBUTION OF THE ORGANIC REMAINS IN THE SEVERAL MAIN GROUPS OF THE MESOZOIC SERIES IN THE BRITISH AREA.

	Cretaceous.			Jurassic.				Triassic.
				Oolitic Series.				
	Upper.	Lower or Neocomian.		Upper.	Middle.	Lower.	Liassic.	Upper. Lower.
GEOLOGICAL EPOCHS.	Chalk. Upper Greensand. Gault.	Lower Greensand.	Wealden and Punfield. Purbeck.	Portland. Kimmeridge.	Coralline Oolite. Oxford Clay. Kelloway Rock.	Cornbrash. Forest Marble. Great Oolite. Fuller's Earth. Inferior Oolite.	Lias.	Rhætic and New Red Sandstone.
1. Mammals[1] ...	...	...	28	...	...	6	...	4
2. Birds	2	...	...	...	...	...	...	...
3. Reptiles	51	3	55	51	15	20	77	2
4. Amphibians ...	...	...	...	...	...	...	...	30
5. Fishes	105	5	35	22	10	67	124	35
6. Cephalopods ...	179	67	2	52	98	98	330	...
7. Pteropods ...	...	...	...	...	...	...	...	...
8. Heteropods ...	1	...	...	...	...	...	...	...
9. Gasteropods ...	221	77	31	47	96	480	393	18
10. Lamellibranchs	266	210	43	136	245	590	454	49
11. Brachiopods ...	51	55	...	15	33	121	130	1
12. Polyzoans ...	80	34	...	...	3	46	7	...
13. Insects	...	...	95	...	...	19	20	...
14. Arachnids and Myriapods ...	...	...	...	...	...	...	...	...
15. Crustaceans ...	96	14	12	10	10	12	40	5
16. Worms (Annelids)	29	12	1	10	12	18	16	...
17. Echinoderms ...	178	23	1	15	39	107	54	1
18. Hydrozoans ...	...	...	...	...	...	...	...	...
19. Corals	68	8	...	1	23	139	84	8
20. Sponges	143	19	...	1	5	18	1	...
21. Foraminifers ...	166	5	...	37	5	...	106	35
22. Plants	14	14	36	2	11	164	15	12
Total ...	1700	547	339	399	605	1905	1851	200

[1] The Mammals, with a few doubtful exceptions, belong to the Marsupialia.

PLATE X.

CRETACEOUS AMMONITES.

Lower Greensand (*Neocomian*).

1. Ammonites (*Olcostephanus*) Asterianus, *D'Orb.*
2. Ammonites (*Hoplites*) Deshayesii, *Leym.*

Gault (*Albian*).

3. Ammonites (*Acanthoceras*) mammillaris, *Schloth.*
4. Ammonites (*Hoplites*) interruptus, *Sby.*
5. Ammonites (*Schloenbachia*) rostratus, *Sby.*

Upper Greensand (*Cenomanian*).

6. Ammonites (*Schloenbachia*) catillus, *D'Orb.*

Lower Chalk (*Turonian*).

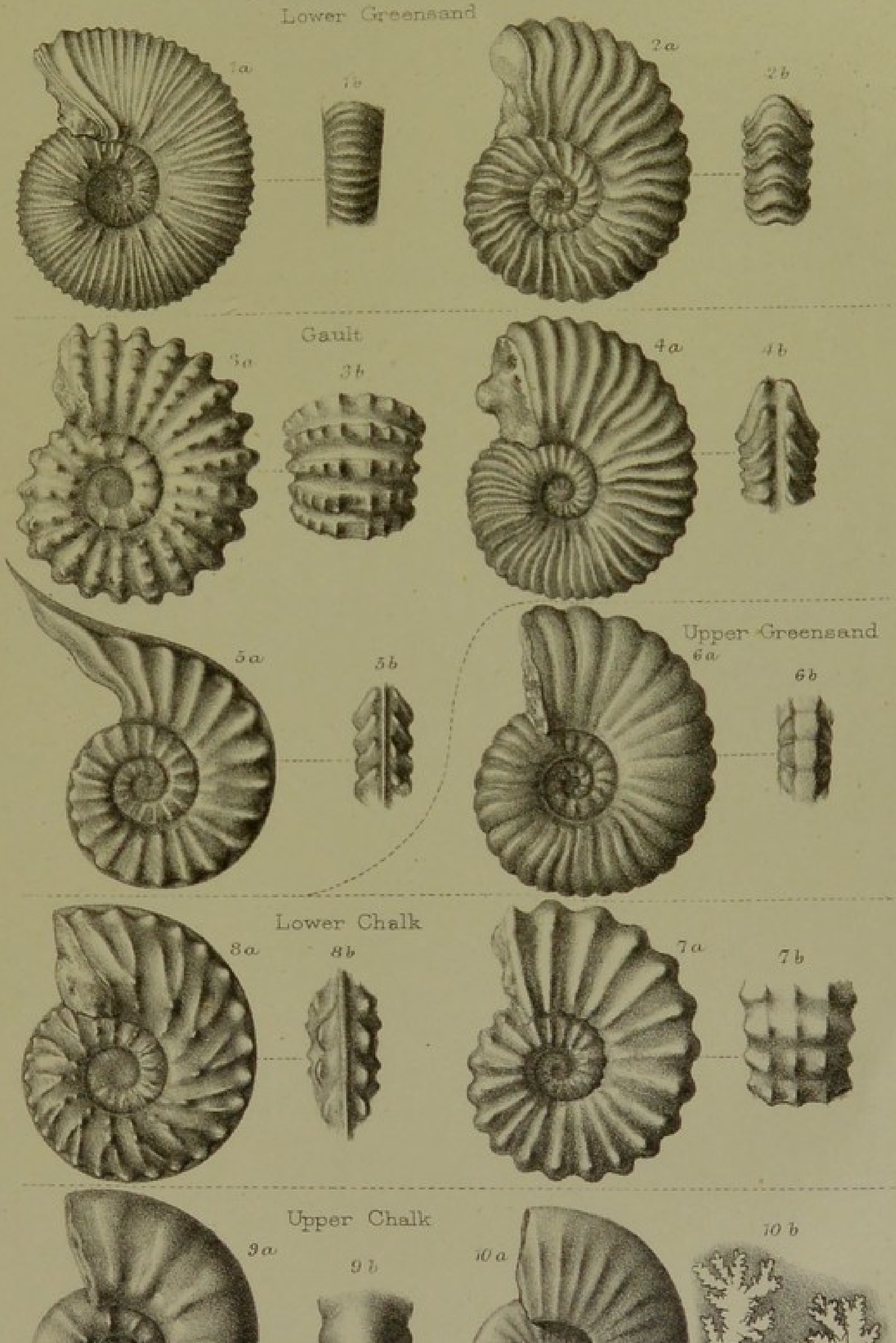
7. Ammonites (*Schloenbachia*) varians, *Sby.*
8. Ammonites (*Acanthoceras*) Rothomagensis, *Brongn.*

Upper Chalk (*Senonian*).

9. Ammonites (*Haploceras*) peramplus, *D'Orb.*
10. Ammonites (*Phylloceras*) leptophyllus (with foliation), *Sharpe.*

Plate X.

MESOZOIC CEPHALOPA:-CRETACEOUS AMMONITES.



G. M. Woodward del. et lith.

PLATE XI.

CRETACEOUS ECHINODERMATA.

Lower Greensand.

1. Trematopygus Faringdonensis, *Wright.*
2. Peltastes (*Salenia*) stellulatus, *Agass.*

Upper Greensand.

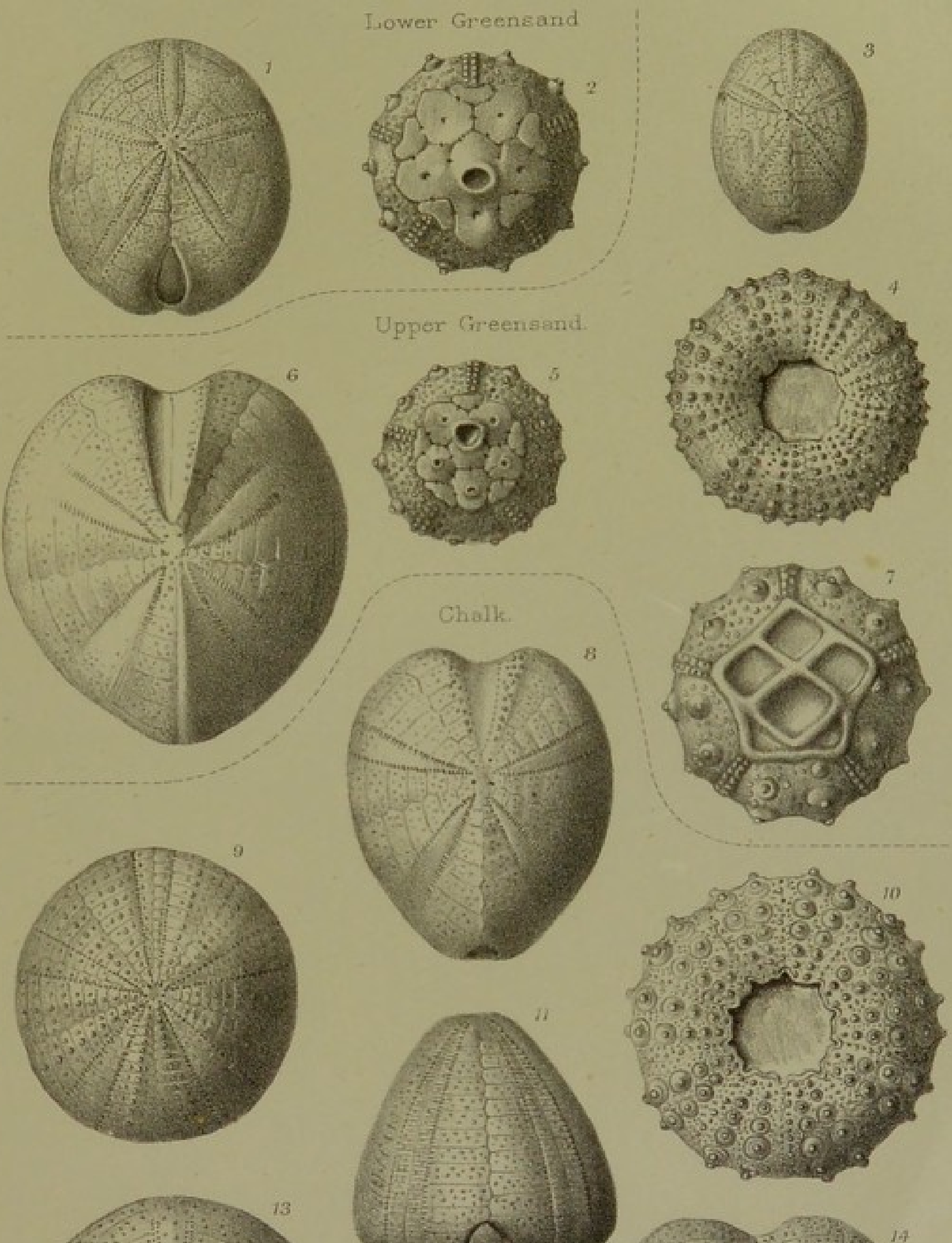
3. Catopygus (*Nucleolites*) columbarius, *Lamk.*
4. Pseudodiadema variolare, *Brongn.*
5. Salenia petalifera, *Desmar.*
6. Cardiaster (*Holaster*) Perezii, *Sismon.*
7. Goniophorus (*Salenia*) lunulatus, *Agass.*

Chalk.

8. Holaster (*Spatangus*) suborbicularis, *Defranc.*
9. Discoidea (*Galerites*) cylindrica, *Lamk.*
10. Cyphosoma (*Echinus*) Kœnigi, *Mantell.*
11. Echinoconus (*Galerites*) conicus, *Breyn.*
12. Pyrina (*Galerites*) ovulum, *Lamk.*
13. Echinocorys (*Ananchytes*) vulgaris, *Breyn.*
14. Micraster coranguinum, *Leske.*

Plate XI.

MESOZOIC ECHINODERMATA,—CRETACEOUS.



G. M. Woodward del et lith.

* Y

PLATE XII.

MESOZOIC MOLLUSCA.

Cretaceous.

Lower Greensand.

1. Diceras Lonsdalii, *Sby.*
2. Exogyra sinuata, *Sby.*
3. Crioceras Duvalli, *Lév.*
4. Gervillia anceps, *Desh.*

Gault.

5. Inoceramus concentricus, *Park.*
6. Hamites (*Anisoceras*) armatus, *Sby.*
7. Ptychoceras adpressum, *Sby.*
8. Cinulia Hugardiana, *D'Orb.*

Upper Greensand.

9. Gryphæa vesiculosa, *Sby.*
10. Exogyra conica, *Sby.*
11. Inoceramus sulcatus, *Sby.*

Lower Chalk.

12. Scaphites æqualis, *Sby.*
13. Inoceramus undulatus, *Mant.*
14. Turrilites costatus, *Lamk.*
15. Terebrirostra Lyra, *Sby.*

Upper Chalk.

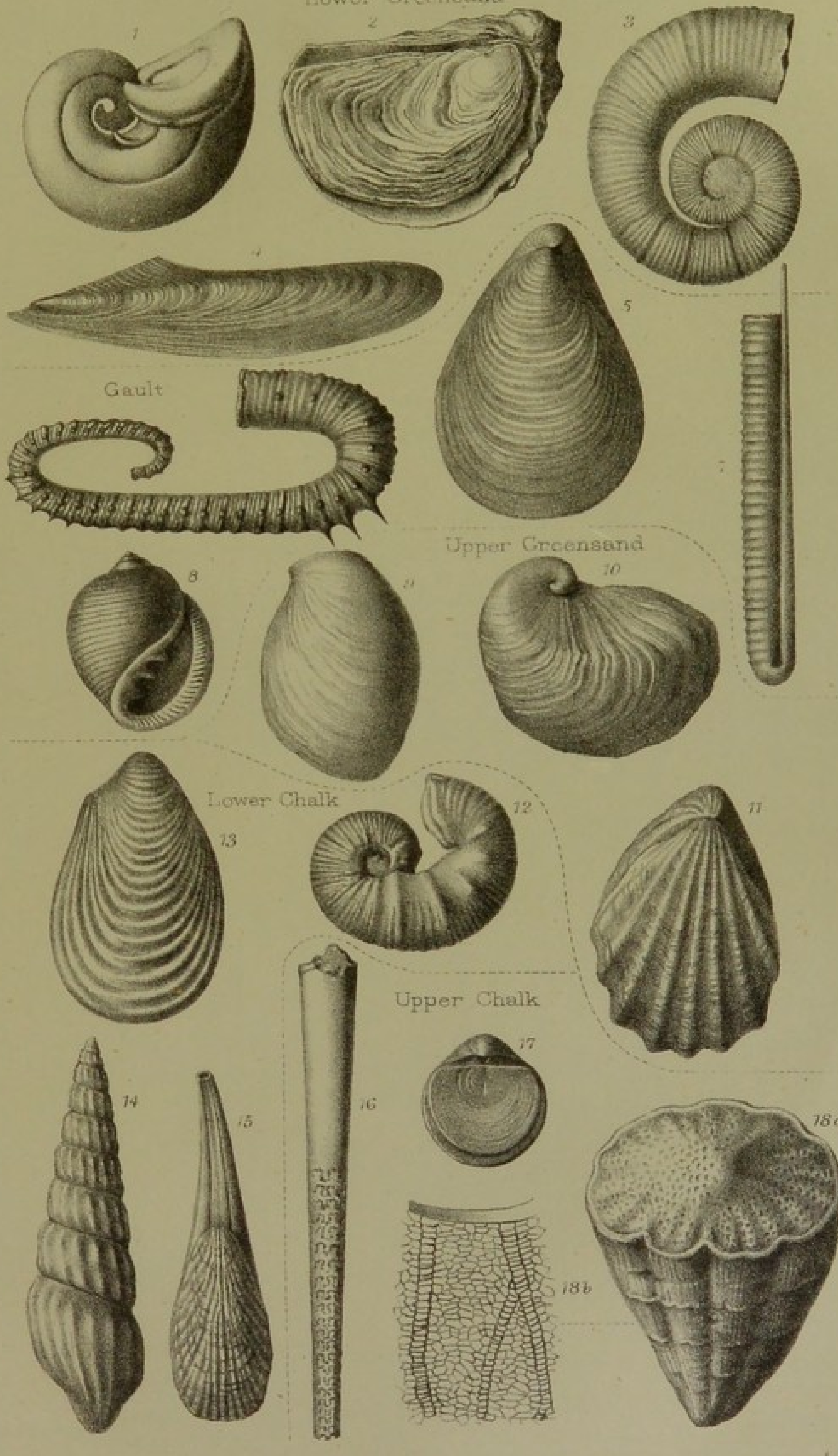
16. Baculites anceps, *Lamk.*
17. Magas pumilus, *Sby.*

18*a*. Radiolites (*Hippurites*) Mortoni, *Mant.*

18*b*. ,, ,, ,, structure of shell.

Plate XII.

MESOZOIC MOLLUSCA: - CRETACEOUS.



G. M. Woodward del. et lith.

CHAPTER XXII.

THE KAINOZOIC OR TERTIARY PERIOD.

THE LOWER EOCENE SERIES[1].

STRATIGRAPHICAL DIVISIONS AND FOREIGN EQUIVALENTS. THE CALCAIRE DE MONS. THANET SANDS AND LOWER LANDENIAN. HEERSIAN BEDS AND THEIR FLORA. CLIMATE. LIMITED RANGE OF THE THANET SANDS AND LOWER LANDENIAN. THE WOOLWICH-AND-READING BEDS. THEIR WIDE EXTENT AND VARIABLE CHARACTERS. PLANT-REMAINS. OTHER ORGANIC REMAINS; ESTUARINE AND FRESH-WATER. SYNCHRONISM OF THE WOOLWICH-AND-READING SERIES. PEBBLE- AND SHINGLE-BEDS. OLDHAVEN BEDS. MARINE BEDS OF EAST KENT. FOREIGN EQUIVALENTS. THE UPPER LANDENIAN. SANDS OF BRACHEUX. THE LIGNITES. THE TRAVERTINE OF SEZANNE. FIRST APPEARANCE OF ORDINARY MAMMALS. THE LONDON CLAY. BASEMENT-BED. ORGANIC REMAINS. RANGE OF THE LONDON CLAY. SYNCHRONISM WITH THE LOWER YPRESIAN AND THE LITS-COQUILLIERS. CLIFFS OF NORTH KENT. THE SHORE OF SHEPPEY. ORGANIC REMAINS. ABUNDANCE OF FISHES AND CRUSTACEANS. FOSSIL FRUITS AND SEEDS. DEPOSIT OF A LARGE RIVER. THE LOWER-BAGSHOT SANDS. OTHER FOREIGN EQUIVALENTS OF THE LOWER DIVISION OF THE LOWER EOCENE. AN EOCENE TRAVERTINE.

THE conspicuous change in composition and in the forms of life between the Cretaceous and the Tertiary strata in North-Western Europe constitutes one of the most striking known instances of a break in the stratigraphical series and in the geological record. We pass at once from strata of considerable uniformity of character, and of great thickness over large areas, to beds peculiarly local in their occurrence, of comparatively small thickness, but of great variety of structure,—and from deposits of comparatively deep, still, marine waters, to those of estuaries, rivers, and shallow seas. The fauna at the same time undergoes a total change. The numerous gigantic Mesozoic reptiles, together with whole families and genera of other classes of the animal kingdom, entirely disappear, and many new orders and families make their first appearance. The species are still more widely affected; for, with one or two doubtful exceptions, not a single Mesozoic species passes up into the Kainozoic strata.

[1] The reader should consult Mr. Whitaker's 'Memoir on the London Basin' in Mem. Geol. Survey, vol. iv. part 1, for a detailed description of the sections and lists of fossils of the Eocene strata around London; and Dixon's 'Geology of Sussex,' edit. by Professor Rupert Jones, 1878, for the same strata in part of the Hampshire Basin.

As the Chalk rose above the sea-level, it underwent extensive marine denudation, to which succeeded atmospheric weathering and subaërial denudation. During this period much of the surface would remain bare and untenanted, so that a considerable length of time elapsed between the emergence of the Chalk and the appearance of a land flora and fauna. A subsequent partial submergence of this area then introduced a marine Fauna, which exhibits no evidence of continuity or of passage-beds, thus showing how long must have been the interval, and how important the geographical changes that then took place.

Stratigraphical Divisions. The divisions of the Tertiary strata established by Lyell, and designated by terms indicating the increasing preponderance of existing forms of life, is one which is both convenient and philosophical, and, although its specific application may no longer hold good in its entirety, and although with the progress of the science it may become necessary to introduce a greater number of subdivisions, still in its broad application and in its general principle it must always hold good. These divisions, with the addition of the 'Oligocene' of Beyrich, are—

Pleistocene (from πλεῖστος, most, and καινός, recent).
Pliocene (from πλεῖον, more, and καινός, recent).
Miocene (from μεῖον, less, and καινός, recent).
Oligocene (from ὀλίγος, few, and καινός, recent).
Eocene (from ἠώς, dawn, and καινός, recent:—the dawn of existing species).

In the older formations, where the genera and species are more wide-spread, there has been little difficulty in taking the respective faunas and floras as a whole, and generally rather than geographically; but, on the principle adopted for the Tertiary strata, those of each Tertiary formation have to be viewed independently in their relations to the existing fauna and flora of the particular zoological province in which the several strata occur. Considering the more specialised conditions of life at the later geological periods, this method becomes, in fact, a necessity for the strata of Tertiary times. In the four conterminous areas the divisions of the Lower Eocene are thus as follows:—

THE LOWER-EOCENE SERIES.

London Basin.

d. London Clay and Basement-bed.*
c. Reading-and-Woolwich beds.*
(* *in part,* Oldhaven beds of Whitaker.)
b. Thanet Sands.
a. *Wanting.*

Belgian Basin.

d. Système Yprésien inférieur.
c. „ Landénien supérieur.
b. „ „ inférieur.
a. „ Montien.

Hampshire Basin.

d. London Clay, Bognor, and Basement-bed.
c. Reading beds (Woolwich beds absent).
b. *Wanting.*
a. *Wanting.*

Paris Basin.

d. Lits Coquilliers of D'Archiac, and 3me étage des Sables Inférieures, Melleville.
c. Argile plastique, Lignites, Glauconie inférieure, and Sables de Bracheux.
b. *Wanting* (?).
a. *Wanting.*

As the area of the Chalk-sea at the close of the Cretaceous period gradually became more and more restricted during emergence, so the early Eocene strata during the first period of the following submergence were of very limited extent, and only gradually spread over wider areas as the

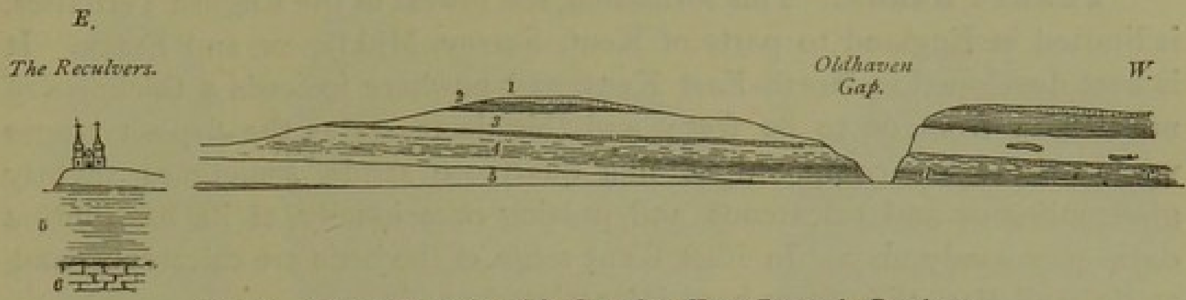


FIG. 166. Section of a portion of the Coast from Herne Bay to the Reculvers.
1. *High-level Gravel with Flint Implements.* 2. *London Clay.* 3. *Basement-Bed of the London Clay.* 4. *Woolwich Beds=Reading Beds.* 5. *Thanet Sands.* 6. *Chalk.*

seas extended and covered fresh lands. The oldest of the Tertiary formations is restricted to a small, but deep, basin around Mons, where it attains a thickness of about 300 feet. It consists of light-coloured marls, concretionary shelly sands, hard calcareous freestones, and siliceous limestones; but it is imperfectly known, as there are no open sections—only well- and shaft-sections.

This deposit was discovered a few years since by MM. Cornet and Briart, who have found in it about 400 species of Mollusca, of which they have described 150 of the Gasteropods[1]. Of these, 138 are new species; and only 12 extend into higher beds. This fauna not only differs greatly from that of the next overlying Lower-Eocene strata, but it bears a considerable resemblance, in general aspect and in the identity of a few species (such as *Voluta spinosa, Oliva mitreola, Buccinum stromboides, Turritella multicostata,* etc.), to that of the much higher group of the 'Calcaire grossier' in the Paris Basin. Together with the marine species, however, there are found a considerable number of land and fresh-water genera, indicating an estuarine, rather than an entirely marine, deposit. Some of these are characteristic of the Woolwich beds, such as *Melanopsis buccinoides* and *Natica infundibulum.*

It is very remarkable to find at the insetting of the Tertiary series a fauna so closely related in its generic characters and by some identical species to that of the Upper-Eocene beds of the Paris and Belgian Basins; while the general characters of the fauna of the succeeding Landenian and Thanet Sands are so perfectly distinct. It seems a case similar to what Barrande contemplated in his Palæozoic *colonies.* Whence came this Montian fauna, in which we have some genera of Gasteropods which appeared during the later Cretaceous or Danian period, with others which

[1] 'Bull. Acad. Roy. de Bruxelles,' 2e sér. t. xx; and Mém., tome xxxvi.

are markedly Tertiary, and with species all new,—and whither these genera migrated to and remained during the long period intervening between the latest of the Mesozoic strata and this the earliest of the Kainozoic strata, is a problem which has yet to be solved.

Thanet Sands. This formation, the lowest of the English Tertiaries, is limited in England to parts of Kent, Surrey, Middlesex, and Essex. It is best developed in North-East Kent, and nowhere exceeds a thickness of more than from 60 to 80 feet; and this decreases as the deposit ranges westward. It is composed of fine quartzose sands, sometimes slightly glauconiferous and calcareous, and passing occasionally, at its base, into a dark-grey sandy clay. In East Kent some of the beds are calcareous, and, at Pegwell Bay, they form hard intercalated bands.

At the bottom of this deposit, and resting directly on the Chalk, is a bed of large angular flints, showing no traces of wear, and covered with a very persistent green coating. This is due to the action of surface-waters that, after percolating through the sands, dissolves and removes the calcareous portion from the coating of the flints, while the iron held in solution enters into combination with the residual free silica. A similar change has taken place at the base of the Reading-and-Woolwich beds, where they rest directly on the Chalk.

Organic remains are abundant at Pegwell Bay and common at the Reculvers; but as the beds range further westward the fossils gradually disappear, owing, it would seem, partly to the beds becoming more sandy and being more exposed to the action of the surface-waters, so that the shells have been dissolved out. Occasional casts, however, of a Cyprina or a Cytherea, without the shell, are preserved in places where the sand inside has become concreted, or where it forms hard bands or blocks, as sometimes happens at Erith and Charlton. The more common and characteristic fossils of the Thanet Sands are—

Foraminifera.—*Cristellaria platypleura*, Jones.
Bivalve Mollusca.—*Cyprina Morrisii*, Sby.; *Cytherea orbicularis*, *Corbula Regulbiensis*, Morris; *Cucullæa crassatina*, Lam.; *Leda substriata*, *Pholadomya Koninckii*, Nyst; *Cardium Laytoni*, Morris; *Sanguinolaria Edwardsi*, Morris.
Univalve Mollusca.—*Fusus subnodosus*, Mor.; *Dentalium nitens*, Sby.; *Ringicula turgida*, D'Orb.; *Scalaria Bowerbanki*, Morris.

Besides the typical cliff-sections at Pegwell Bay near Ramsgate, and at the Reculvers, there are pit-sections at Erith, Charlton, Lewisham, Purfleet, Richborough, and other places; while railway-cuttings pass through these sands at Canterbury, Faversham, Sittingbourne, Chatham, St.-Mary-Cray, Croydon, and Epsom[1].

The Lower Landenian (Dumont) strata of Belgium are the exact equivalents of the Thanet Sands. Their dimensions and general petro-

[1] The Author in 'Quart. Journ. Geol. Soc.,' vol. vii. p. 235.

logical characters are precisely alike; and their organic remains present a very close correspondence. *Cyprina Morrisii*, *Corbula Regulbiensis*, *Cucullæa crassatina*, *Pholadomya Koninckii*, *Sanguinolaria Edwardsi*, etc., are

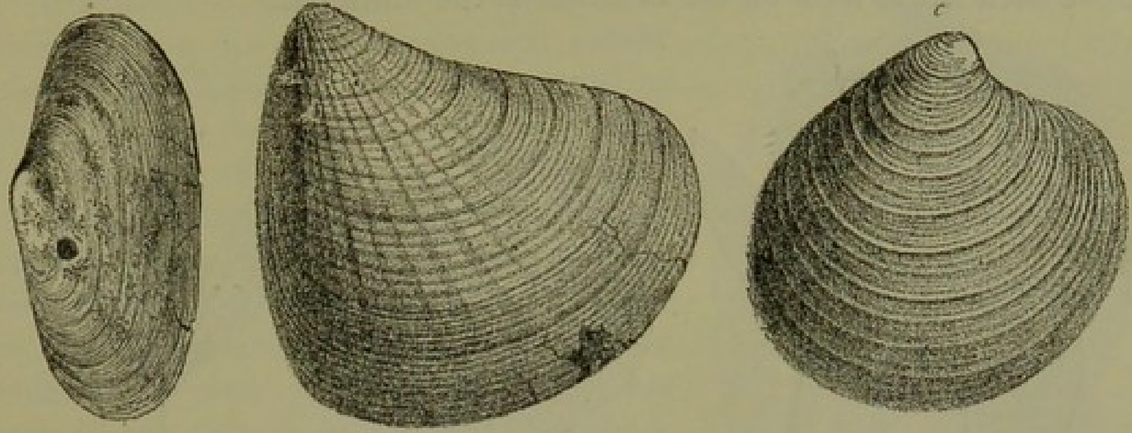


FIG. 167. Shells of the Thanet Sands.
a. Sanguinolaria Edwardsi, Mor. *b. Pholadomya Koninckii*, Nyst. *c. Cytherea orbicularis*, Edw.

the common fossils there as they are in this country. MM. Rutot and Vincent[1] have, however, more recently added a large number of new and peculiar species to this Belgian fauna, bringing up the number of invertebrate fossils to ninety-four species.

Between the Lower Landenian and the 'Calcaire de Mons' the Belgian geologists place a small group of strata, also of limited range, termed 'Heersian,' remarkable for the interesting flora found at Gelinden. There seems to me, however, hardly sufficient reason why these beds should be separated from the Lower Landenian. They differ in petrological characters, being a pure hard white marl, with subordinate quartzose and glauconiferous Sands; but this is merely a local character, dependent probably upon the proximity of a chalk land. They contain very few Mollusca; but amongst them are *Pholadomya cuneata*, *Modiola elegans*, *Cyprina Morrisii*, and *Nucula Bowerbanki*, all Lower-Landenian or Thanet-Sands fossils. It contains also a few peculiar species of Fish, but these do not afford any term of comparison; though one belongs to a Chalk genus, others are of Eocene and Miocene genera.

The Heersian Plants, however, are exceptional, and constitute the oldest known European Tertiary flora. They occur at Gelinden near Liége and have been described by Count de Saporta[2]. Oaks resembling those of mountainous districts of the temperate zone predominate. One of these closely resembles the *Quercus pseudosuber* of Spain and Algiers. With these are Laurels, Chesnuts, Willows, Ivy, Aralia, and other plants. Altogether the group is very different from the tropical Palms, Tree-ferns,

[1] 'Ann. Soc. Géol. de Belg.' Mém. vol. vi. p. 69.
[2] 'Le Monde des Plantes,' p. 213.

etc., which characterise so distinctly some of the later Eocene Tertiaries. The woods of Southern Japan, according to Saporta, now present a very similar assemblage of trees. That the climate of the Thanet-Sands period was one of a temperate rather than a hot character is a conclusion I had before been led to form on the evidence of the Mollusca.

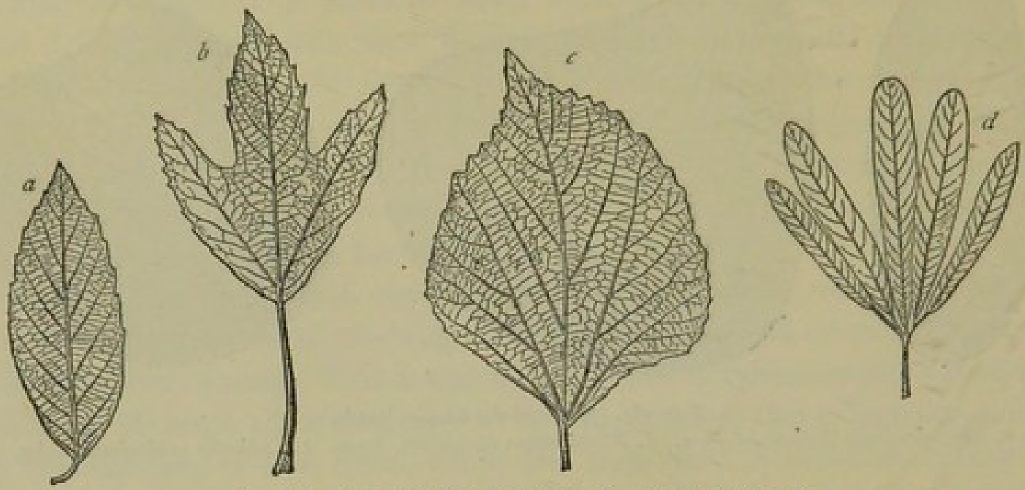


FIG. 168. Heersian Plants of Gelinden. (After *Saporta.*)
a. Quercus parceserrata, Sap. and Mar. *b. Aralia Looziana*, Sap. and Mar. *c. Viburnum vitifolium*, Sap. and Mar. *d. Dewalquea Gelindenesis*, Sap. and Mar.

At the same time it is to be observed, that the discovery of the Mons beds shows that a more southern type of Mollusca, as evidenced by such genera as Oliva, Mitra, and Voluta, preceded in this case the more northern type. The fluctuation of climate which this indicates may have been due to local geographical changes of land and sea, or to some more general cause.

The Lower Landenian does not extend beyond Belgium and the borders of France; but the Upper Landenian passes transgressively southward on to the Chalk, forming the Lower-Tertiary outliers of the Woolwich period, so numerous on the high chalk-plains of Picardy. On the northern borders of the Paris Basin other marine Lower-Eocene sands are met with at Beauvais, Laon, and Rheims, which have been referred to the Lower Landenian and the Thanet Sands; but I think it more probable that the Bracheux Sands, which are often very fossiliferous, belong to the lower zone of the Woolwich series; some of the sands, however, of the more northern districts of the Soissonnais and Laonnais may possibly belong to the Lower-Landenian age.

THE WOOLWICH-AND-READING BEDS.

This group—the most widely spread of our Tertiary strata—presents one of the best possible examples of the variation of structure, composition, and distribution of organic remains due to difference of local conditions. In the western area of the London Basin the beds of this age consist of massive mottled clays, with subordinate laminated clays and intercalated sands. All of these, except occasionally a few feet at their base, are destitute of organic remains. In the central area they consist of thick pebble-beds and sands, and carbonaceous clays and lignites, with a profusion of estuarine and fresh-water remains, intercalated with a few unproductive and pebbly seams of the same mottled clay; while, as they range still further eastward, these clays disappear, and the whole of the beds pass into glauconiferous sands with exclusively marine remains. It is for this reason that the double name, indicating the districts where the typical characters of each group are best exhibited, is used[1]. Over these two areas there is one feature in common—which is, that the Basement-bed consists of a thin seam of impure greensand, full usually of large unworn flints with some small flint pebbles, frequently accompanied by a bed of large Oysters, the *Ostrea Bellovacina*. This fossil has a wide range on this horizon, where it often forms banks, with the oysters commonly in the position in which they lived, and with both valves entire.

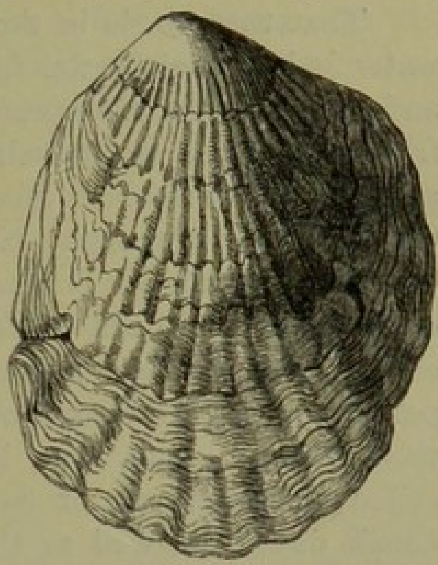


FIG. 169. *Ostrea Bellovacina*, Lam.

The Reading Beds. The best known of the pit-sections is the one originally described by Dr. Buckland at Katesgrove on the Kennet at Reading. The basement-bed contains, in addition to the *Ostrea Bellovacina*, the fragmentary remains of Turtles, teeth of Shark, and Crustacea[2], showing that marine conditions prevailed at first over the whole area, not only of the Thanet Sands, but over that larger land area which was gradually submerged at the close of the Thanet-sands period.

FIG. 170. Railway-Cutting, Kembridge, near Romsey, Wilts.
a. Flint gravel, 2 to 8 ft. b. Mottled red and grey clays, 15 ft. c. Light greenish sands with a bank of Ostrea bellovacina, 4 ft. d. Chalk.

The beds which succeed the more uniform Oyster-bed are extremely variable, consisting, in Berkshire, of light and buff-coloured sands, often showing oblique lamination, with irregular beds and lenticular masses of

[1] See 'Quart. Journ. Geol. Soc.,' vol. x. p. 75.

[2] The surface of the Chalk is also often perforated by what seem to be holes left by boring annelids, or, according to Messrs. Hudleston and Rupert Jones, by the roots of sea-weeds; the holes are now filled with green sand and loam.

mottled, red, grey, black, and purple clays, and a few subordinate beds of light-grey laminated clay; while in the Hampshire Basin (Alum Bay, Fig. 189, p. 374, and White-Cliff Bay) thick massive mottled clays prevail exclusively.

That these beds in the London Basin were accumulated in shallow water is indicated by the frequent oblique lamination caused by currents, and by the occasional presence in the sand beds of rolled and rounded fragments of the mottled clay derived by erosion from the associated beds, as shown in the sections given by Professor Rupert Jones and Captain (now Colonel) King of the clay-pit at Coley Hill, Reading [1].

Sandstones. The sands also occasionally contain concreted blocks, or irregular local beds, of sandstone—sometimes with a very hard siliceous cement. It is these masses [2] which, after the denudation of the softer portions of the strata that originally spread over the chalk hills far beyond their present limits, were left behind and now form the isolated blocks called Grey-wethers, or Sarsen stones, scattered on the surface of the Chalk downs, as well as the streams of stones on the floor of many of the Chalk valleys, especially those to the west of Marlborough. It is these residual blocks, and not blocks brought from a distance, that supplied the monoliths for Stonehenge, Abury, and other druidical monuments of that district. The blocks were at one time far more numerous than now on the Chalk hills, but their use for road-material, building-stones, gate-posts, paving-stones, and farm-purposes, is leading to their gradual destruction and removal.

These sandstone blocks occasionally contain flint pebbles and angular flints. In Buckinghamshire and Hertfordshire the pebbles are so numerous that the sandstone passes into a conglomerate, which, like the 'Druid sandstones' in Wiltshire, has resisted denudation, and been left as isolated blocks on the surface of the ground. They are known as the Hertfordshire Puddingstones [3].

Their Origin. The origin of these siliceous sandstones and conglomerates is probably connected with the presence of the mottled clay, with which they are co-extensive, decreasing in quantity as the clays decrease in importance. These clays, which are very plastic and are much used for pottery and tiles, are really an impure kaolin (Vol. I. p. 49), derived in all probability from old decomposing granitic and gneissic areas formerly stretching to the west and south-west of this Tertiary district. I imagine

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[1] 'Quart. Journ. Geol. Soc.,' vol. xxxi. p. 451.

[2] Mr. Whitaker and Prof. Rupert Jones think that in Berkshire and Wiltshire they are more frequently derived from the Bagshot Sands, 'Quart. Journ. Geol. Soc.,' vol. xviii. p. 258; and 'Wilts Mag.' Dec. 1886.

[3] It is rarely that this Puddingstone is found *in situ*. There is, however, a shallow pit in, and another near, Shenley Park, Herts. where it may be seen. In a few places the matrix is calcareous.

that the soluble silica set free at the same time aggregated in a colloid state amongst the quartz sand-grains, and thus effected the siliceous cementation of the previously loose sands. This cementation is sometimes so complete that the grains of sand seem as though fused and run together, and the flint pebbles are so completely incorporated with the matrix that the jointing of the beds, and the fracture caused by a blow, run equally through both the matrix and the inclosed pebbles.

It is possible also that the condition of the waters, charged with the alkaline salts, resulting from the decomposition of the felspathic rocks, may have had something to do with the singular absence of animal remains in the mottled clays, an absence not confined to the London Basin, but prevailing equally in the Paris Basin. Occasionally shells are found in some of the associated sands; but these occur low down in the series, and no

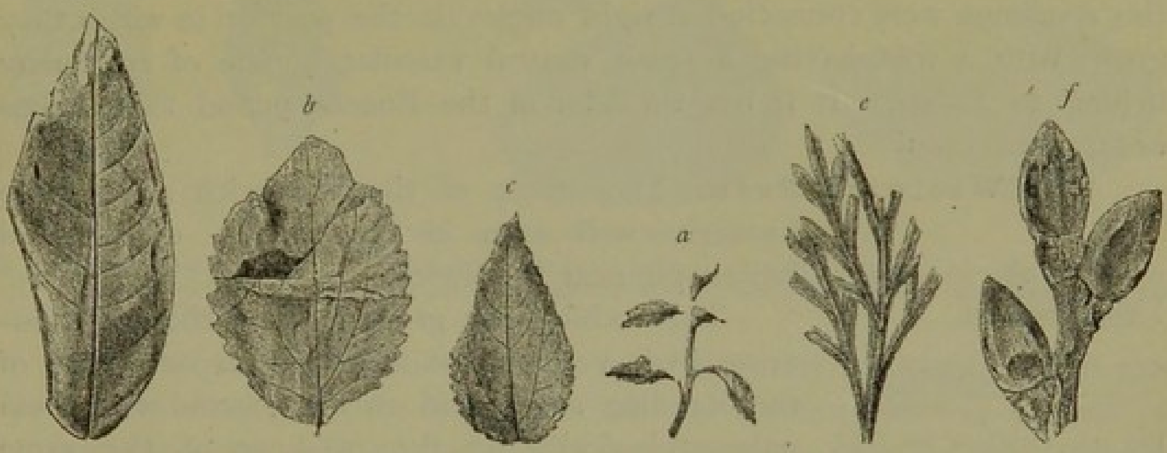

FIG. 171. Leaves from the Reading plant-bed.

a. Laurel. b. and c. Fig. d. Dryanoides. e. Fragment of frond of Fern (Asplenium ?). f. Buds of a Dicotyledonous Tree.

fossils have been found in the overlying pure clay beds. At Coley Hill there is a sandy bed in which I have found fragile impressions and casts, probably of *Nucula*, *Cardium*, *Tellina* (?). In the London district, where on the same horizon fossils abound, the mottled clays are absent.

Plant Remains. At Reading there occurs, amongst the lower sands and a few feet above the Chalk, a bed of laminated clay full of the plant remains admirably preserved; the leaves, with all their venation, are entire, showing they could not have been drifted from any great distance. But, although they are in this perfect state, no seeds nor flowers are found with them, consequently their relations are somewhat conjectural [1]. They have, however, been referred by De la Harpe and others to species of Laurel, Fig, Robinia, Aralia, Plane, Oak, and Fern,—a group agreeing in many of its genera with that of Gelinden in the Heersian of Belgium.

[1] Sir J. Hooker, 'Quart. Journ. Geol. Soc.,' vol. x. p. 163.

In the associated sand-beds pieces of wood and stems of trees are met with, but they are permeated with limonite, and so much decomposed, that, although the woody structure is easily recognisable, they are too friable to allow of sections being made for microscopic examination; but by observing the specimens in a certain light, the structure peculiar to coniferous trees can be recognised. Silicified masses of wood, having large irregular cavities, as if macerated, were found in these sands in a railway-cutting north of Newbury.

Besides this wood and the leaf-impressions, both of which are of restricted occurrence, other plant remains, generally indeterminable, are common in the scattered blocks of Sarsen Stones on the Berkshire and Wiltshire downs. They have all the appearance of rootlets of trees growing on a sandy soil. An unusually perfect specimen recently examined by Mr. Carruthers[1] led him to conclude that some of these rootlets, which in this specimen were connected at right angles (in the position in which they grew) with a root having a small central vascular bundle of cells, may belong to *Palms*. It is not till later in the Eocene period that Palms became common.

The Woolwich Beds. The strata of the Woolwich series were formerly well seen in the section of the old ballast-pit near Woolwich.

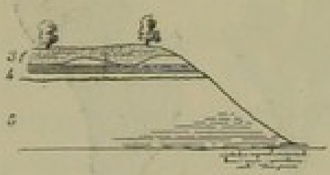

FIG. 172. Section of the Woolwich beds between Woolwich and Charlton.
3. *Pebble-bed.* 4. *Woolwich-and-Reading beds.* 5. *Thanet Sands resting on Chalk.*

This exhibited a group of fluviatile and estuarine beds very unlike in every respect those of the Reading series, and only connected with them palæontologically by the presence of the same characteristic oyster (*Ostrea Bellovacina*), the teeth of Lamna, and the remains of Turtles. The Molluscan remains of the Woolwich beds were very abundant there, although the number of species was not large. The beds formed two divisions—the lower marked by the prevalence of fresh-water and of estuarine conditions, and the upper division by more marine conditions. Both divisions showed considerable variation, and with the recurrence of similar lithological conditions the same species reappear in each of them.

Organic Remains. In the clay beds of the Woolwich series, where the more fluviatile and estuarine conditions obtain, the characteristic fossils are,—

Cerithium variabile, *Desh.*	Cyrena cuneiformis, *Sby.*
Melania inquinata, *Defr.*	Cyrena deperdita, *Sby.*
Melanopsis buccinoides, *Desh.*	Ostrea tenera, *Sby.*
Hydrobia Parkinsoni, *Mor.*	O. Bellovacina, *Desh.*

1 'Geol. Mag.,' Decade iii. vol. ii. p. 361. See also a paper by Prof. Rupert Jones in 'Wiltshire Magazine,' vol. xxiii. p. 122.

In the overlying sands and pebble-beds there are also, in addition to most of the above, other characteristic species, including—

Buccinum fissuratum, *Desh.*
Calyptræa trochiformis, *Lam.*
Fusus latus, *Sby.*
Melanopsis ancillaroides, *Desh.*
Natica glaucinoides, *Sby.*
Neritina consobrina, *Fér.*
Cardium Plumsteadiense, *Sby.*
Pectunculus terebratularis, *Desh.*
Cyrena tellinella, *Férussac.*
Nucula fragilis, *Desh.*
Modiola Mitchelli, *Mor.*
Psammobia Condamini, *Mor.*

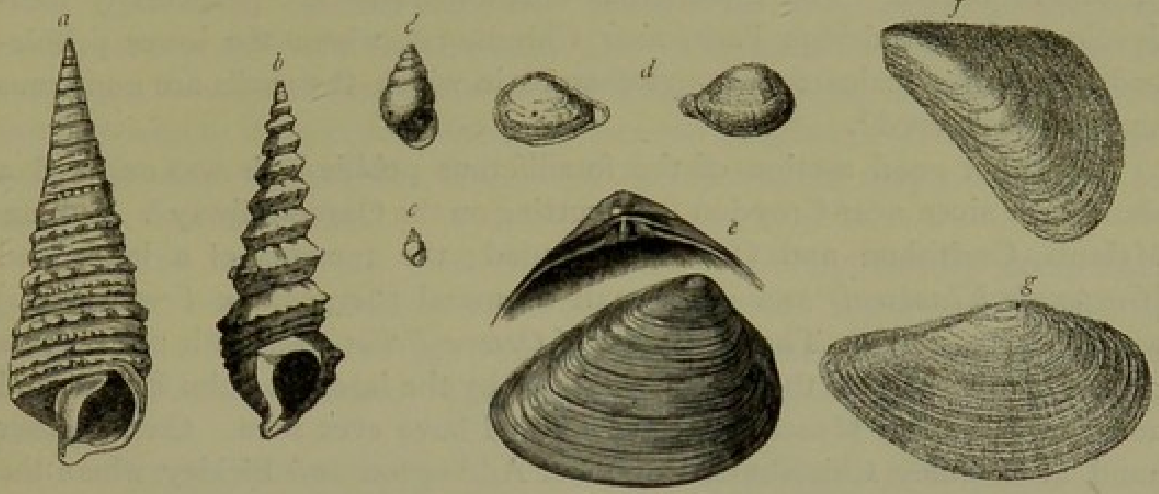

FIG. 173. Mollusca of the Woolwich Beds.

a. Cerithium variabile, Desh. *b. Melania inquinata*, Defr. *c. Hydrobia Parkinsoni*, Mor., nat. size (*c'* enlarged). *d. Corbula Regulbiensis*, Mor. *e. Cyrena cuneiformis*, Sby. *f. Modiola Mitchelli*, Mor. *g. Psammobia Condamini*, Mor.

In some places the conditions are more distinctly fresh-water, as at the New-Cross cutting of the Brighton Railway, where there was a band of impure limestone full of *Paludina lenta*, together with a few Uniones (*U. subparallelus*) and numbers of the small *Hydrobia Parkinsoni*. Below this bed are sands with the same estuarine species as at Woolwich. At Peckham and Dulwich, in addition to the fossils of the Paludina-bed of New Cross, there are some species (*Cyrena Dulwichiensis* with marks of the colour-bands, and *Pitharella Rickmani*) peculiar to this area, together with remains of Mammalia (*Coryphodon*) and of Reptiles (*Chelonia* and *Crocodilia*).

Teeth of Lamna are common in almost all the beds, with a few vertebræ of Elasmobranch and Teleostean fishes, and scales of *Lepidotus*.

The Flora of the fluviatile beds of the Lewisham district is more varied than that of the synchronous beds at Reading. Amongst them are Ferns allied to Osmunda, and Asplenium (?); Conifers of the genera Libocedrus and Pinus; and Dicotyledonous trees belonging to Platanus, Ficus, Cinnamomum and Aralia (?). Specimens of these have been found at Dulwich, Bromley, Lewisham, and Herne Bay[1]. They occasionally form seams of lignite.

[1] For information on the Flora of the whole of the Eocene strata of the London and Hampshire Basins, the student should consult the papers of Baron von Ettingshausen in 'Proc. Roy. Soc.,' vol. xxviii–xxx, and the Monographs by Mr. J. Starkie Gardner in the volumes of the Palæontographical Society for 1879–1884.

Synchronism of the Woolwich-and-Reading Series. Notwithstanding the very different characters presented by the two typical sections of Reading and Woolwich there can be no doubt of the synchronism of the strata. For in the intermediate area the sands and mottled clays of the former district become intercalated with the sands and pebble-beds of the latter district; and as one series of strata disappears the other takes its place. The pebble-beds are in some places fossiliferous, in others barren. The fossiliferous conglomerates are particularly well-developed at Sundridge Park, near Chiselhurst, where the lower pebble-beds pass into a calcareous conglomerate, in which the shells are numerous and well preserved [1].

Another good section of the fossiliferous pebble-beds was exposed a short time since near Croydon by a cutting on the Oxted railway [2]. Cyrena, Melania, Cerithium and Ostrea abounded; the remains of a large bird (*Gastornis Klaasseni*) and of a small Mammal (*Coryphodon Croydonensis*) were also met with. The specimens of *Ostrea Bellovacina* with both valves perfect, at the base of the series, collected by the late Mr. John Flower and now in the Oxford Museum, are the finest I have ever seen. On the other hand, at Bromley, Chiselhurst Common, Addington, and Bickley, where the pebble-beds form a loose permeable surface-gravel, they contain no fossils.

This absence of fossils in the pebbly sands, which are extremely permeable, is, no doubt, due to the shells having been removed, together with all calcareous matter, by the solvent action of the surface-waters; for, when the beds are consolidated or protected, organic remains are usually present, together with more or less calcareous matter.

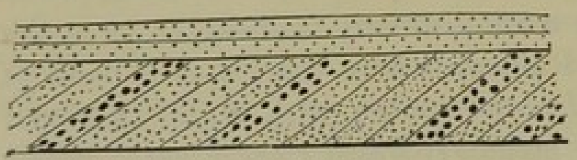

FIG. 174. *Section of the Pebble Beds of the Woolwich- and Reading-Series, in the railway-cutting, Bickley, Kent, showing oblique and horizontal lamination.* Depth 10 feet.

As this group of strata ranges eastward, the pebble-beds die out, but the fluviatile and carbonaceous clays and sands are prolonged to the neighbourhood of Newington, near Faversham. A typical section of these beds is exposed in a pit at Upnor, on the banks of the Medway, opposite Chatham. In East Kent, the fluviatile beds gradually disappear, and they are altogether wanting in the fine cliff-section of the Lower Tertiaries between Herne Bay and the Reculvers (Fig. 166), where, as well as at Richborough, the whole series is arenaceous and marine.

Mr. Whitaker [3] places the upper pebbly portion of the Woolwich

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[1] Masses of the *Ostrea tenera*, evidently in the position in which they lived and grew, are often adherent to large flint pebbles.

[2] See Mr. Klaassen's paper in 'Proc. Geol. Assoc.,' vol. viii. p. 126, and Mr. E. T. Newton's in vol. ix. p. 348; and 'Trans. Zool. Soc.,' 1886.

[3] 'Quart. Journ. Geol. Soc.,' vol. xxii. p. 412.

Series, including the Sundridge beds, together with the 'Basement-bed' of the London Clay, in a separate division, which he terms the 'Oldhaven Beds,' from Oldhaven Gap between Herne Bay and the Reculvers. I cannot, however, look upon those beds, which there and at Upnor are restricted to the Basement-bed proper, as the equivalents of the fossiliferous conglomerates of Sundridge, Bromley, and the other places he refers to, which, I think, it is not possible to separate from the Woolwich-and-Reading Series as a whole. At the same time there is, no doubt, great difficulty in many instances, where the London Clay is absent, to draw the line of separation between the Basement-bed of the London Clay and the Woolwich beds, or even to determine whether the present position of some of the great superficial banks of pebbles, like those of Blackheath, may not be due to still later 'remaniements.'

Marine Beds. In East Kent, where entirely marine conditions prevail, we find, in addition to Woolwich species, a certain number of species which have passed up from the Thanet Sands, together with a few new and peculiar species. The fossils there characteristic of this zone are—

Corbula Regulbiensis, *Mor.*
Cucullæa crassatina, *Lam.*
Cyprina Morrisii, *Sby.*
Cytherea orbicularis, *Mor.*
Pectunculus terebratularis, *Desh.*
Sanguinolaria Edwardsi, *Mor.*
Natica subdepressa, *Mor.*
Buccinum fissuratum, *Desh.* (?)
Fusus subnodosus, *Mor.*
Glycimeris Rutupiensis, *Mor.*
Cardium Plumsteadiense, *Sby.*
Cardita pectuncularis, *Desh.*

There are here none of the great banks of pebbles, nor of the fluviatile and carbonaceous clays of West Kent. They are replaced entirely by quartzose green sands with marine fossils often in a silicified state, *Corbula Regulbiensis* being especially common. Silicified fragments of wood showing structure and perforations made by the Teredo or Teredina are also common in these sands at the Reculvers and Richborough. Some silicified cones of a peculiar pine have also been found.

A further variation in the lower part of this series takes place at Richborough. The ruins of the 'Castle' stand on glauconiferous sands in which all the fossils, like many of those in the same bed at Herne Bay, are in the state of siliceous casts; and they include some species, such as *Cyprina scutellaria*, not found elsewhere in the English area. This addition is important, as it serves to correlate this zone with a zone in the Paris Basin, of which, though the French beds are richer in organic remains, it is apparently (from superposition and community of certain species) the equivalent.

I have dwelt at some length on the variation of type in this series of beds, on account of its instructive character and easy demonstration[1].

Foreign Equivalents. The same characters which distinguish this

[1] See the 'Quart. Journ. Geol. Soc.,' vol. x. p. 75.

zone in England mark it equally well in France, and in a less degree in Belgium. In the Paris Basin there are similar local developments of bright red mottled clays in certain areas (Meudon, Vaugirard, Montereau, etc.), and of fluviatile clays and lignites in others (Beauvais, Soissons, Epernay, etc.), associated in places with marine sands (Bracheux, Laon, Rheims, etc.). In Belgium the fluviatile characters are less marked. The Upper Landenian, which is the equivalent of the Woolwich-and-Reading beds, there consists chiefly of light-coloured quartzose and glauconiferous sands, with occasional sandstones, and rarely with subordinate local beds of plastic clays and lignite. The only fossils, with the exception of some individuals of *Ostrea Bellovacina*, are a few scarce specimens of *Cyrena cuneiformis* and *Melania inquinata*, found beneath the Ypresian (London) Clay in Artesian wells at Ostend and Ghent. Occasional impressions of plants, and fragments of silicified wood like those of the Reculvers, are also met with.

The Lower Landenian of Belgium and the Thanet Sands of Kent have been considered to be the equivalents of the 'Glauconie Inférieure' or 'Sables de Bracheux' of the Paris Basin; but, for reasons before given, I think that the former do not extend so far south, and that they are lower in the series than the latter.

The Lignites with sands and pebble-beds, such as we have in the Woolwich series, are underlain, it is true, in the neighbourhood of Beauvais by 20 to 30 feet of fossiliferous marine pebbly sands, known as the 'Sables de Bracheux.' These sands contain about seventy species of Mollusca; and, although some of them are Lower-Landenian or Thanet-Sands species, they are such as, in this country, range up into the Woolwich series; while there are a certain number of other species which are peculiar to the latter and are never found in the lower strata. Although the sands of Bracheux are richer in species than the Woolwich beds, this is due to the circumstance that the marine conditions only obtain in a very small area in this country, where the sea-bed may also have been less favourable for shells. Nevertheless, the following species, which are common and characteristic of the Woolwich series of East Kent, occur also at Bracheux:—

Corbula Regulbiensis, *Mor.*
Cyrena cuneiformis, *Sby.*
Cyprina scutellaria, *Desh.*
Cucullæa crassatina, *Lam.*
Ostrea Bellovacina, *Lam.*
Nucula fragilis, *Desh.*
Calyptræa trochiformis, *Lam.*
Cerithium variabile, *Desh.*
Fusus latus, *Sby.*
Melania inquinata, *Defr.*
Melanopsis buccinoides, *Desh.*
Pectunculus terebratularis, *Desh.*

The 'Lignites' of the Paris Basin, like the fluviatile beds in this country, are subordinate to the Sands; but they are of greater extent and importance there than here, and seem to range higher, possibly to the level of the Basement-bed of the London Clay. The lower beds of this series have also, in the Oise and Soissonnais, greater dimensions, and are more fossiliferous.

There are both in France and in England local and limited fresh-water deposits possessing special characters. Amongst the most remarkable of these is that of the 'Sables' and 'Calcaire de Rilly,' between Rheims and Epernay. The calcareous tufa, with its abundant and special lacustrine and land shells[1], lies at the base of the 'Lignite' series, and rests on a surface of marine quartzose sands. It has evidently been formed in a shallow fresh-water mere or lake in which a large species of Physa abounded, together with species of Cyclas, etc., whilst peculiar species of Pupa, Helix, and Cyclostoma were carried in by the surface-waters.

The mere was probably fed by a thermal spring highly charged with carbonic acid, and these waters in percolating through the underlying marine sands (the equivalent in Champagne of the 'Sables de Bracheux') removed all the soluble and foreign ingredients (and all the shells), leaving the sand so snow-white and pure as to render it suited for the manufacture of plate-glass. At a little distance off the same sands are found with their usual impurities (slight though they are) of colour and foreign matter, and with their usual marine shells.

Another local and more massive travertine, occurring on nearly the same horizon at Sézanne, contains the abundant remains of a luxuriant flora, rich in Ferns, large Laurels, Magnolias, Figs, Ivy, Vines, etc. M. de Saporta states that they are of forms still living in the southern part of the temperate zone, mixed with others now restricted to hotter climates. In this travertine no shells have been found. It seems to be a purely sub-aërial calcareous deposit, possibly formed by a hot spring.

Higher in the series are other lignite beds, which contain a flora of more varied forms than the preceding. It consists of Palms, Bamboos, Myricaceæ, etc., and shows that the climate was gradually attaining the higher temperature which prevailed in the later part of the Eocene period.

It is in the Lower-Eocene Series that ordinary (placental) Mammals first appear in the European area. Remains of the Coryphodon have been found in the neighbourhood of London, as also near Paris; those of the Arctocyon at La Fère (Oise). I have found teeth of Lophiodon (together with a vertebra of Serpent) in the Lignites of Epernay; while M. Lemoine has discovered in beds of the same period, in the neighbourhood of Rheims, remains of three new Mammals[2] with those of two Birds—the Gastornis and Eupterornis. Arctocyon was a carnivorous animal with Marsupial affinities, and is restricted to these Lower-Tertiary beds. The Lophiodon and Coryphodon (a tapir-like animal) had a much wider range both vertically and horizontally.

This stage marks a period of elevation, when the Thanet Sands and adjacent tracts became covered by estuarine, fluviatile, and shallow-water

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[1] See M. De Boissy's paper in 'Mém. Soc. Géol. de France,' 2e sér., vol. iv. p. 147.
[2] 'Bull. Soc. Géol. de France,' 3e sér., vol. x. p. 96.

deposits, indicating the proximity of land. On these lands flourished forests of trees, such as might belong to a warm temperate climate. The lands were also peopled by a Mammalian fauna, of some variety, associated with large birds and various reptiles. Whence these came we have at present no clue. Either there were, in all probability, older Tertiary strata, or during some stages of the Cretaceous period there must have been land-areas, from which the incoming of this terrestrial population may hereafter be traced.

The London Clay.

This formation consists of a very uniform mass, having a maximum thickness of 400 to 500 feet, of dark bluish-grey clay, weathering brown, and of a sandy and pebbly Basement-Bed, generally not more than two to three feet thick, but expanding to a thickness of 20 feet in East Kent, where it forms part of the 'Oldhaven Beds' of Mr. Whitaker. Small as this 'Basement-Bed' is, it possesses some marked and persistent features of interest. It points to an apparently abrupt subsidence affecting an area comprising the whole of the South-east of England and a great part of Belgium and Northern France, and extending across the Channel from Hampshire to the coast of Normandy.

The Basement-Bed. At White-cliff Bay, in the Isle of Wight, the Basement-Bed rests on an eroded surface of the *Mottled Clay*, of which it encloses rounded fragments or balls, together with pebbles of flint and chalk. It is there three to four feet thick, and is well characterised by its fossils, which are especially abundant in some thin subordinate calcareous bands. Although no thicker, and generally indeed thinner, this bed is very constant in the Hampshire Basin; and it is possible that the well-known fossiliferous Bognor Rocks[1] may be only a larger local shell-bank of this zone. The common and abundant fossils of this bed, which occur also all through the London Clay, are—

Ditrupa plana.
Natica labellata, *Lam.*
Rostellaria Sowerbyi, *Mant.*
Vermicularia Bognoriensis, *Mant.*
Calyptræa trochiformis, *Lam.*
Pectunculus brevirostris, *Sby.* Fig. 177 *c.*
Cytherea obliqua, *Desh.* Fig. 177 *e.*
Cardium Plumsteadiense, *Sby.*
Ostrea pulchra, *Sby.*
Teeth of Lamna. Fig. 185 *c.*

In the London Basin, where portions of this bed are often concreted into large tabular masses, the Basement-Bed ranges, with little or no change, and with but few additional fossils, from Hungerford to London. At the Sonning-Hill railway-cutting, near Reading, and at Hedgerley Dean near Slough, it proved to be singularly rich in fossils. In both places the *Ditrupa plana* occurs in myriads, and the *Pectunculus* is very

[1] See Dixon's 'Geology of Sussex,' 2nd edit., by Prof. Rupert Jones, pp. 70, 273.

abundant. At Hedgerley the large calcareous blocks are full of fine calcitic casts of *Rostellaria* and *Natica*. Sections of this bed are of frequent occurrence in consequence of the underlying mottled clays being largely worked for bricks and tiles.

The Basement-Bed may be traced through Essex into Suffolk; but it has there lost its usual fossils (teeth of the Lamna excepted), and is represented by a thin bed of small flint pebbles. It was in this bed at Kyson, near Woodbridge, that the small marsupial (*Didelphys Colchesteri*) and the two species of *Hyracotherium* were found.

It is not always easy to follow the Basement-Bed in Surrey and West Kent. It is well-marked, however, at Upnor, near Chatham, and assumes still larger dimensions and importance at Herne Bay (Fig. 166), where it contains, besides the fossils before-named, several additional London-Clay species.

With the exception of a few shells of the Woolwich series, which range thus high, all the fossils of the Basement-Bed are those of the London Clay. Most of the Lower-Tertiary (Landenian) forms here die out; and many London-Clay species make their first appearance.

The London Clay extends through the Hampshire Basin[1], reappears near Newbury, and thence ranges uninterruptedly to Herne Bay, maintaining everywhere the same characters of a tenacious clay with layers of septaria and occasional thin glauconiferous seams.

This clay also extends into French Flanders and Belgium, where it is known as the 'Lower Ypresian' system. It has proved as yet, both in the Pas-de-Calais and in the greater part of Belgium, curiously barren of organic remains, Foraminifera alone excepted. But in the neighbourhood of Mons (Morlanwelz) there has lately been discovered a bed of clay, overlying the Upper Landenian and about 30 feet thick, which apparently represents either the London Clay or its Basement-Bed, for it contains, amongst other fossils, *Ditrupa plana*, *Panopæa intermedia*, *Nucula fragilis*, *Pyrula Smithii* (?), *Xanthopsis bispinosus*, together with *Nummulites planulatus*.

There is also a small outlier of the London Clay on the French coast at St. Marguerite, near Dieppe. In the Department of the Oise-and-Aisne, the London Clay is represented in part by the 'Lits Coquilliers' (D'Archiac) of Cuise Lamotte, or possibly more exactly by the central division of the 'Sables Inférieurs' (Melleville) of the Laonnais and Soissonnais.

As the London Clay is, with the exception of the beds immediately at its base and those at top, generally too stiff for brick-making, there are few sections to be met with unless in wells, railway-cuttings, and cliff-sections. Of the last, the long line of section of the upper part of the London Clay

[1] Although much altered in the neighbourhood of Poole.

in the Isle of Sheppy is celebrated for the number and variety of its organic remains, which, however, must be sought for washed out on the shore, and not in the clay-cliffs.

The lower beds of the London Clay are, with the underlying Woolwich beds, well exposed in the cliffs east of Herne Bay; but organic remains are there scarce. In the cliffs nearer Whitstable are found the beautifully preserved small cones of a species of *Sequoia* (*S. Richardsonii*, Fig. 179, *i*) cast in iron-pyrites.

In the Sheppey cliffs the fossils are mostly in the state of pyritous casts, which, unfortunately, easily decompose, and are therefore most difficult to preserve for any length of time. Casts of seeds, fruits, and shells, washed out of the cliff as it falls down, may be picked up in thousands on the shore at low water. A few fossils are also preserved in the calcareous nodules and blocks of septaria.

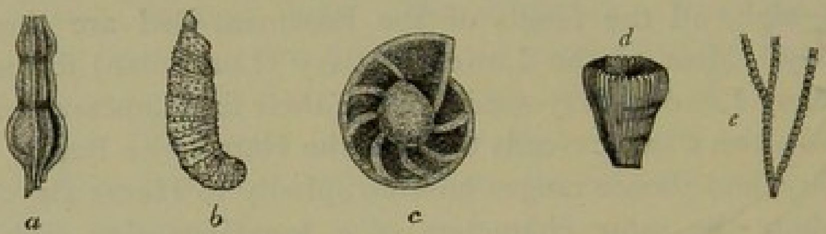

FIG. 175. London-Clay Foraminifers, enlarged; and Corals, nat. size.
a. Nodosaria Badenensis, D'Orbigny, × 10. *b. Merginulina Wetherelli*, Jones, × 10. *c. Cristellaria cultrata*, Montfort, variety, × 10. *d. Paracyathus caryophyllus*. *e. Websteria crisioides*.

Organic Remains. In a thin seam met with in sinking a well in the Isle of Sheppey, Mr. Shrubsole not long since discovered some Diatomaceæ, including an abundant species of *Coscinodiscus* ('R. Microsc. Soc. Journ.,' 1881). Professors Rupert Jones and W. K. Parker have enumerated a considerable number of Foraminifera[1] from the London clay, of which the most common are species of *Nodosaria*, *Dentalina*, and *Textularia*.

The Cœlenterata are few and small, such as live in deep waters; the most characteristic being *Turbinolia Bowerbanki*, M. Edw., *Paracyathus caryophyllus*, Lam., and *Dasmia Sowerbyi*, M. Edw., *Graphularia Wetherelli*, M. Edw. (Pl. XV, fig. 10).

Echinoderms are also scarce; but one small Urchin, *Cœlopleurus Wetherelli*, Forbes (Pl. XV, fig. 6), is common at Sheppey, and *Hemiaster Branderianus*, Forb. (Pl. XV, fig. 1), is found at Hampstead; while a pretty Brittle-Star, *Ophiura Wetherelli*, Forbes, abounds in the upper beds at Highgate; the *Pentacrinus sub-basaltiformis*, Forbes (Pl. XV, fig. 11), also belongs to this period.

Amongst Annelids, *Vermicularia Bognoriensis* is very abundant and characteristic of the lower beds especially.

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[1] The many species recently found in diggings in London are figured and described by Messrs. Sherborn and Chapman in the 'Journ. R. Microsc. Soc.,' ser. 2, vol. vi.

Crustacea abound in the higher divisions. Specimens of *Xanthopsis Leachii*, *Hoploparia Belli*, and *Dromolites Bucklandi* are extremely common on the Sheppey shore. In some beds Ostracoda are also common; *Cythereis Bowerbankiana*, *Cytherella Londinensis*, and others being distinctive species.

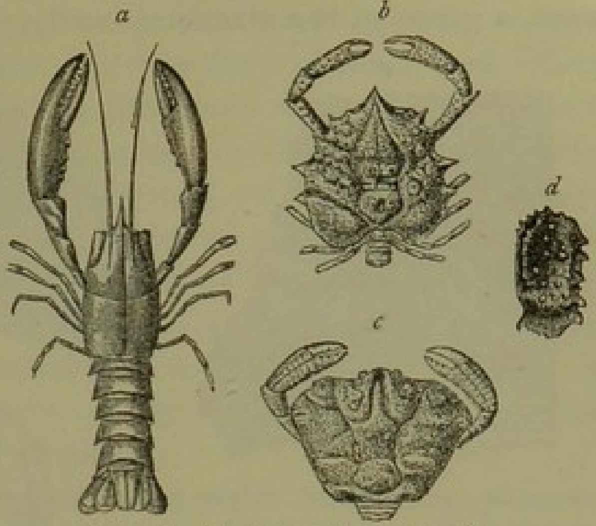

FIG. 176. Crustacea of the London Clay.
a. Hoploparia gammaroides, M'Coy. *b. Dromolites Lamarckii*, Desm. *c. Xantholites Bowerbankii*, Bell. *d. Cythereis Bowerbankiana*, Jones, 12/1.

Lingula tenuis, Sby., and *Terebratulina striatula*, Sby., are the only Brachiopods. Polyzoa are rarely met with.

About 140 species of Lamellibranchiates and 160 species of Gasteropods have been recorded, of which the most typical are:—

Avicula arcuata, *Sby.*
Cryptodon angulatum, *Sby.* Fig. 177, *d.*
Cyprina planata, *Sby.*
Modiola elegans, *Sby.*
Nucula similis, *Sby.*
Panopæa intermedia, *Sby.*
Pholadomya margaritacea, *Sby.*
Cultellus affinis, *Sby.* Pl. XIII, fig. 22.
Teredina personata, *Lam.* Fig. 177, *f.*
Aporrhais Sowerbyi, *Mant.*
Conus concinnus, *Sby.*
Fusus bifasciatus, *Sby.*
Ovula retusa, *Sby.* Pl. XIII, fig. 21.
Pleurotoma rostrata, *Sby.* Pl. XIII, fig. 14.
Pyrula Smithii, *Sby.*
Rostellaria ampla, *Brand.*
Solarium patulum, *Lam.*
Pseudoliva fissurata, *Desh.* Pl. XIII, fig. 4.
Cancellaria læviuscula, *Sby.*

The Cephalopoda are few, but characteristic, such as *Nautilus centralis*, Sby., Pl. XV, fig. 3, *N. imperialis*, Sby., *Aturia zic-zac*, Sby., Pl. XV, fig. 4, *Belosepia sepioidea*, Blainv., and *Beloptera Levesquei*, D'Orb.

Together with some fossils very common in the Basement-bed and the lower part of the London Clay, a rare minute fresh-water shell belonging to an East-Indian genus, nearly allied to *Physa*, and now living in the marshes of Nazirpur, is represented in Fig. 177, *g*. It had escaped detection until lately discovered in nests in some septaria at Sheppey by Mr. Shrubsole[1].

The London Clay is rich in remains of Fishes, there being ninety-three known species, chiefly from Sheppey. A few Sharks, Rays, and Ganoids are met with in the Woolwich, Lower-Landenian, and Heersian strata, but the London Clay is the first formation in which the bony or Teleostean fishes occur plentifully. Though these Fishes made their first appearance in the later Cretaceous period, they were limited in the Chalk to eighteen genera; whilst in the London Clay there are some fifty-nine genera. Amongst the common species are, *Sphyrænodus crassidens*, allied to the modern Barra-

[1] Col. Godwin-Austen. 'Quart. Journ. Geol. Soc.' vol. xxxviii, p. 218.

cadus—voracious fishes of tropical and sub-tropical seas—*Cybium macropomum*, a genus of the mackerel family, inhabiting the tropical Atlantic and

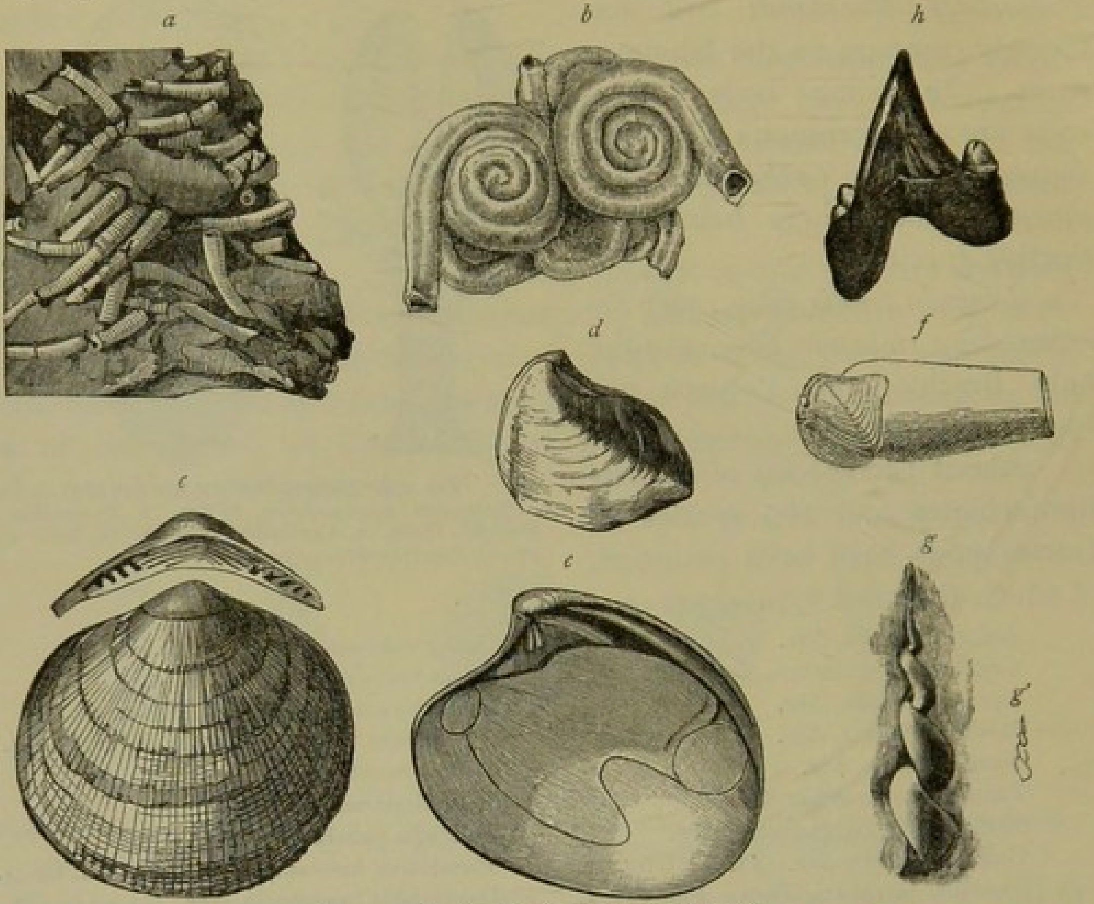

Fig. 177. Various Fossils of the London Clay.
a. Ditrupa plana, Sby. *b. Vermicularia Bognoriensis*, Mant. *c. Pectunculus brevirostris*, Sby. *d. Cryptodon angulatum*, Sby. *e. Cytherea obliqua*, Desh. *f. Teredina personata*, Lam. *g. Camptoceras priscum*, H. H. Godwin-Austen. *g'.* nat. size. *h. Tooth of Otodus obliquus*, Ag.

Indian Oceans, and *Phyllodus Toliapicus*, one of the family of the Wrasses, —littoral fishes very abundant in temperate and tropical zones.

At the same time Rays and Sharks (including a Carcharodon probably not less than 40 feet in length) still continued to be the predominant class, the most common being:—

Myliobatis Colei, *Ag.*
M. Toliapicus, *Ag.* Fig. 185, *b.*
Pycnodus Toliapicus, *Ag.*
Otodus obliquus, *Ag.* Fig. 177, *h.*
Lamna elegans, *Ag.* Fig. 185, *c.*
Elasmodus Hunteri, *Egert.*

Of Birds six species have been found; one, according to Owen, was a species of small Vulture (*Lithornis Vulturnus*); another probably of the Kingfisher family (*Halcyornis Toliapicus*); also a species of Heron, and a remarkable web-footed bird, the *Odontopteryx Toliapicus*, with *teeth*, thus having Pterosaurian characters.

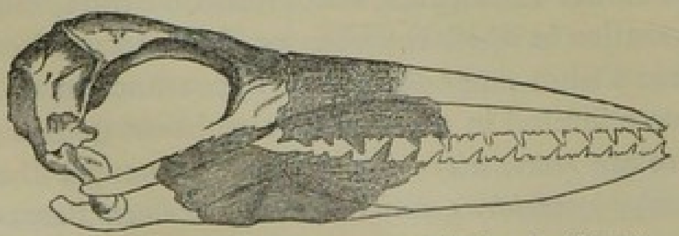

Fig. 178. *Skull of Odontopteryx toliapicus*, $\frac{2}{3}$. (Owen.)

Of the Reptiles, the characteristic feature is the abundance of marine and fresh-water Chelonians. Owen remarks that more species of true Turtles have left their remains in the London Clay of Kent and Essex (fifteen) than are now known to exist in the whole world. One of them (*Chelonegigas*) was of gigantic size, its head being 18 inches long by 14½ wide. The remains of a serpent (*Palæophis Toliapicus*), 12 feet long, have also been found, together with those of two species of true Crocodile (*Crocodilus champsoides* and *C. Toliapicus*) related to the Gavial of the Ganges.

Amongst the five species of Mammalia are *Hyracotherium leporinum*, a small pachyderm allied to *Chæropotamus*, and *Pliolophus vulpiceps*, a hoofed herbivore allied to *Palæotherium*. They all belong to the Tapiridæ of South America but have Malayan affinities.

Plants. The fossils which constitute the most interesting palæontological feature of this Formation are the Plants, the remains of which are equally remarkable for their state of preservation and their unique character. Instead of leaf impressions, to which much uncertainty attaches, or an occasional flower or seed, the flora of the London Clay is represented almost solely by fruits and seeds, with trunks of trees and fragments of wood. These fruits are, like most of the shells, in the state of pyritous casts, and generally entire[1]. Any number of them may be collected on the Sheppey strand, though very few are found elsewhere.

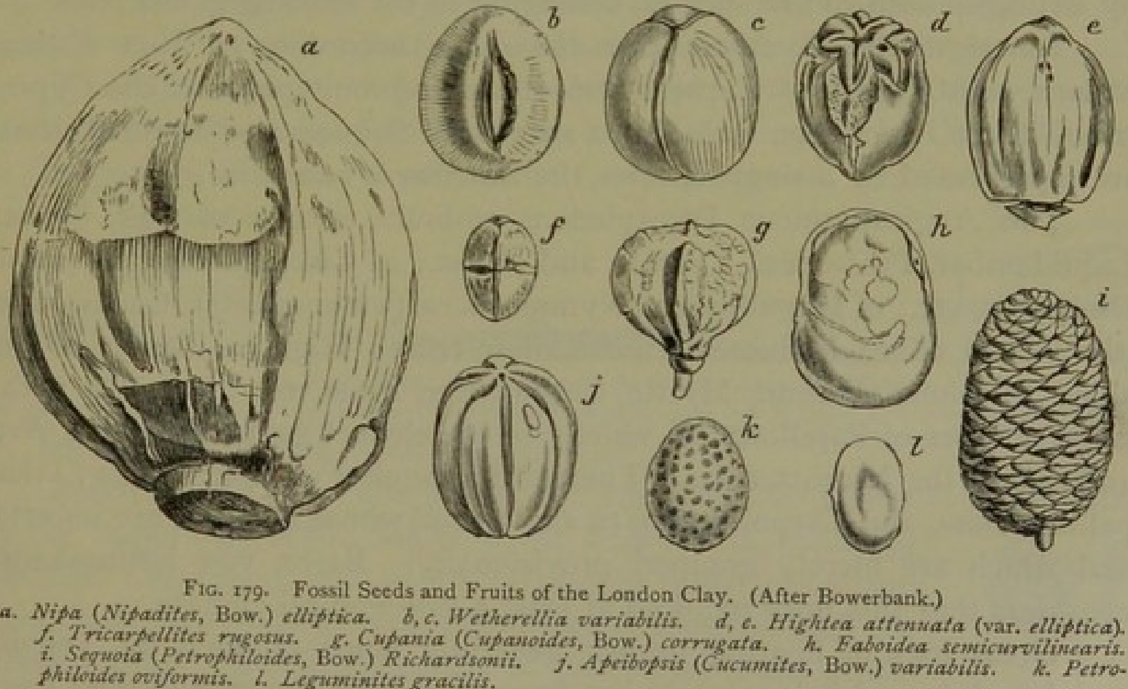

FIG. 179. Fossil Seeds and Fruits of the London Clay. (After Bowerbank.)
a. *Nipa* (*Nipadites*, Bow.) *elliptica*. b, c. *Wetherellia variabilis*. d, e. *Hightea attenuata* (var. *elliptica*). f. *Tricarpellites rugosus*. g. *Cupania* (*Cupanoides*, Bow.) *corrugata*. h. *Faboidea semicurvilinearis*. i. *Sequoia* (*Petrophiloides*, Bow.) *Richardsonii*. j. *Apeibopsis* (*Cucumites*, Bow.) *variabilis*. k. *Petrophiloides oviformis*. l. *Leguminites gracilis*.

In consequence of these essential parts of the plant being preserved, botanists have been enabled to refer these remains with much certainty to their analogous living genera. These fruits have also given a clue to the

[1] The specimens should be kept in bottles of boiled water or in oil; or, if exposed, they should be well varnished, to prevent decomposition.

determinations of some of the plants in the Hampshire strata, where leaves alone have, with few exceptions, had to be depended upon.

Some years ago the late Dr. Bowerbank published an account of the more abundant of these fruits and seeds, but the work was left unfinished[1]. Many forms were, however, correctly determined and well figured, especially the *Nipadites*. Some of these are given in Figure 179.

More complete investigations have lately been made by Baron von Ettingshausen[2] and Mr. J. Starkie Gardner[3]. The former in his preliminary report states that the fossil Flora of Sheppey contains at least seventy-two genera and two hundred species, which may be distributed into forty-one families. Some can be identified with living genera.

The Monocotyledons are represented by an Agave, a Smilax, a Musa, and two species of Amomum, together with as many as eleven genera of Palms, including four Sabals (Fan Palms), one Chamærops (a dwarf Fan-Palm) and two Areca (the Cabbage Palm). But the most common palm of Sheppey is the *Elais eocænica*, which is nearly allied to the living *E. melanococca* (an African Oil-Palm).

Closely allied to the Palms are the Pandanaceæ or Screw-pines, of which the fruits ('Nipadites' of Bowerbank) are the most abundant of all the Sheppey plants. They are known to the collectors there by the name of 'fossil figs.' The twelve species enumerated by Bowerbank are reduced by Ettingshausen to five species, belonging to the existing genus Nipa.

Amongst the Gymnosperms there are, according to Von Ettingshausen, eight genera of Cupressineæ—including four species of the Cypress tribe—three Abietineæ, including a species of Sequoia; while the Taxineæ are represented by a single species, the *Salisburia eocænica*.

The Angiospermous Dicotyledons embrace species of Oak, Walnut, Liquidambar, Proteaceæ, Laurels, and Nyssa; of Cinchonidium, Strychnos, Diospyros, etc.; of Magnoliaceæ, Nymphæaceæ (water-plants); Cucurbitaceæ (the Gourd tribe), Malvaceæ (the mallow tribe; Hightea, *Bow.*); of trees allied to Lime, Chesnut, Myrtle, Cotoneaster, Plum, etc.; together with a large number of Papilionaceæ, chiefly of the extinct genus Faboidea, *Bow.*, and one of the Mimosa tribe. There are a number of other Plants (Tricarpellites, *Bow.*, and Carpolithes, *Ett.* and *Gard.*) whose affinities are uncertain and which are merely grouped provisionally. Baron von Ettingshausen considers that this flora required at least a sub-tropical climate.

Great logs of floating timber, generally honey-combed by Teredina and Annelids, and belonging to coniferous trees, are common in the London Clay; and fossil resin has been found at Highgate.

All the palæontological evidence tends to show that the London Clay

[1] 'Hist. Foss. Fruits and Seeds of the London Clay,' Part I, p. 144, with 17 plates. 1840.

[2] 'Proc. Roy. Soc.,' vol. xxix. p. 388.

[3] 'Palæontographical Society's Monographs,' 1879 to 1885.

was the muddy deposit of a large river, like that of the Ganges or Mississippi, flowing through a country possessing a tropical climate, and bringing down, like those rivers, into its estuary and bordering sea, specimens of the vegetation and animals of the lands through which it flowed, and where they became imbedded with the remains of the contemporary marine organisms of that period.

Thus Professor Owen remarks[1] in speaking of the Crocodilian remains of the Eocene period in Britain, that 'Crocodiles, Gavials, and Alligators now require, in order to put forth in full vigour the powers of their cold-blooded constitution, the stimulus of a large amount of solar heat, with ample verge of watery space for the evolutions which they practise in the capture and disposal of their prey. Marshes with lakes, extensive estuaries, large rivers, such as the Gambia and Niger that traverse the pestilential tracts of Africa, or those that inundate the country through which they run, either periodically, as the Nile, for example, or with less regularity, like the Ganges; or which bear a broader current of tepid water along boundless forests and savannahs, like those ploughed in ever-varying channels by the force of the mighty Amazon or Oronooko,—such form the theatres of the destructive existence of the carnivorous and predaceous Crocodilian Reptiles. And what, then, must have been the extent and configuration of the Eocene continent which was drained by the rivers that deposited the masses of clay and sand, accumulated in some parts of the London and Hampshire Basins to the height of one thousand feet . . . . . .'

The following section shows the relation generally of the Tertiary to the Cretaceous strata in the London Basin, and of the Bagshot or Upper Eocene to the London Clay and Sands of the Lower Eocene to one another.

FIG. 180. Diagram-section from Godalming across the Hog's Back to the Chobham Ridges.
a. Upper Bagshot Sands. b. Middle Bagshot Sands = the Bracklesham beds in part. *c. Lower Bagshot Sands. d. London Clay. e. Reading-and-Woolwich Beds. f. Chalk. g. Upper Greensand. h. Gault. i. Lower Greensand.* The Thanet Sands do not extend so far west.

France. In the Paris Basin, the London Clay group is represented by the upper part of the Sands of the Soissonnais, including the *Lits Coquilliers*, which are extremely fossiliferous, and have about thirty-one species of Mollusca in common with the London Clay. A leading feature of this series is the profusion of the *Nummulites planulatus*,—a species occurring also in the Belgian Basin, but of doubtful occurrence in England. As they range southward, these lower Sands pass under the Calcaire Grossier, and are not met with in the southern part of the Paris Basin.

FIG. 181. *Nummulites planulatus*, Lamarck, nat. size.

[1] 'Monogr. Foss. Reptilia,' Palæont. Soc. 1850, p. 49.

THE LOWER BAGSHOT SANDS.

In the London Basin the London Clay is succeeded by beds of light-coloured quartzose sands, 100 to 120 feet thick, interstratified with which are a few irregular and local thin beds of brown, grey and white laminated clays containing a few imperfect vegetable remains. No other fossils have been found except a few crumbling and indeterminable sandstone casts of shells, which I met with some years ago in a sand-pit at Cooper's Hill. In general appearance and character, there is little to distinguish these beds from the Upper Bagshot Sands, with which they have been grouped on lithological grounds. I now however believe that these sands should be grouped with the London Clay, from which they are separated by no very well defined line.

In Belgium the London Clay (Lower Ypresian) is overlain in the western districts by similar unfossiliferous sands (Upper Ypresian), which increase in importance in their range eastward, while the argillaceous strata with which Dumont associated them gradually thin out, or pass into sands. Lately MM. Rutot and Vincent have found in the Ypresian sands, in the neighbourhood of Brussels, a considerable number of fossils, including such common London Clay species as—

Nautilus centralis, Sby. (Pl. XV, fig. 3); *Turritella scalaroides*, Sby.; *Vermicularia Bognoriensis*, Sby.; *Pecten corneus*, Sby.; *Pectunculus decussatus*, Sby.; *Lucina squamula*, Desh.; *Ditrupa plana*, Sby.; together with *Nummulites planulatus*, Lam.

With these, there are a still larger number of the species belonging to the Lower Sands of the Soissonnais and *Lits Coquilliers*.

Insect remains, belonging to *Curculionidæ* and *Buprestidæ* (and allied possibly to *Helopidium* and *Agrilus*), together with a large winged Ant, have been found in the Lower Bagshots of Corfe and Wareham.

In the Hampshire Basin, these sands are equally unfossiliferous; and in places the divisional lines are still more obscure. In Alum Bay, where the beds between the London Clay and the Barton Clay are represented in a long series of bright-coloured sands, clays, and lignites, the exact equivalents of the Bracklesham beds of Whitecliff Bay cannot be determined in consequence of the absence of fossils (see Fig. 189, p. 374). If they belong, as at Whitecliff Bay, to the middle of the section, we shall have, as the equivalent of the Lower Bagshot, the beds from No. 7 to 19 (?) inclusive of my original section [1]. It was in one of these, namely No. 17, a seam two to three feet thick of very fine laminated clay [2] of a cream or a light-fawn colour, that I discovered the finely preserved plant-remains, afterwards

[1] 'Quart. Journ. Geol. Soc.,' vol. ii. 1846, p. 223, &c., pl. 9.

[2] When last at Alum Bay (1882), I could find no traces of this bed, which must have formed one of those local lenticular seams so common in this series, and have thinned out.

described by De-la-Harpe and Heer. Amongst them were species of Conifers (*Cupressites taxiformis*, Ung.), various evergreen trees including Laurels, Figs, a Walnut with very large leaves, three species of Proteaceæ, including a *Banksia* closely allied to *B. latifolia* of Australia, and several genera of Leguminosæ. The leaves of *Apeibopsis Laharpæ* were considered by Heer to belong to the tree which furnished the fruit named *Cucumites variabilis*, Bow., of Sheppey. Altogether forty-eight species of plants have been determined, which, on the whole, show a greater affinity with the Lower than with the Upper Eocene strata.

According, however, to Baron von Ettingshausen[1], the number of species at Alum Bay amounts to 274, distributed among 116 genera, indicating a sub-tropical climate. Of these, thirty-one genera are common to Alum Bay and Sheppey, and this close connection makes it, he thinks, inadvisable to distinguish the leaves of the one from the fruits of the other by separate specific names, even though they cannot be absolutely connected. The smaller number of Palms at Alum Bay is, however, remarkable; but this may be due to the preservation of leaves in one case and not in the other. Amongst noticeable but rare forms are the characteristic leaves of *Aristolochia* and of *Alayxia*, allied to the living *A. spicata*, and of a *Clerodendron* allied to the East-Indian *C. viscosum*. There are thirty-eight species of *Papilionaceæ*. The Baron remarks, as a very striking fact in connection with the Alum-Bay Flora, that more than fifty species are common to the Sotzka and Hæring deposits.

A similar Flora, but in which fine and large specimens of Palms are more preponderant, is found in beds of the same age near Wareham and Studland.

For these reasons I would now place the Lower Bagshot Sands in the Lower Eocene division and associate them with the London Clay. The classification of the Lower Eocene will therefore stand as under—

Lower Eocene	Lower-Bagshot Sands.
	London Clay and Basement-Bed.
	Woolwich-and-Reading Beds.
	Thanet Sands.
	The Mons Beds of Belgium (*wanting in England*).

Other Foreign Equivalents of the Lower Division of the Lower Eocene. It is doubtful how far strata of this age extend over Southern and Eastern Europe. The Thanet Sands do not extend beyond the Département du Nord or to the northern part of the Aisne. The Woolwich-and-Reading Beds overlap them, and spread over the whole of the northern portion of the Paris Basin. The London Clay proper is confined to the Anglo-Belgian Basin, though beds probably their equivalent, if not passage-beds—the Sables Inférieurs of the Soissonnais—fringe the northern

[1] 'Proceed. Roy. Soc.,' vol. xxx. p. 228; see also Starkie Gardner, *Op. cit.*

section of the Paris Basin, but without extending so far south as the Lignite-beds of the Marne.

It is possible that some of the Lower-Nummulitic strata of the Pyrenees may be synchronous with the London Clay; but no beds of this age appear to exist in the Western Alps, though in the more eastern parts there may possibly be some such beds; nor are there any in Germany or in other parts of Central or Eastern Europe.

At the same time, it is possible that some of the isolated fresh-water and lacustrine deposits in the South of France, such as that with *Physa prisca* and *Nummulites Ramondi* at the base of the Nummulitic series in the Corbières, the travertine with plant-remains at St. Gély in the neighbourhood of Montpellier, and the red marls and limestones of Langesse in Provence with *Physa*, *Limnæa*, *Planorbis*, etc., may belong to the period of the Sands of the Soissonnais, or to the period between the Thanet and Bracklesham beds; but the correlation of distant fresh-water strata must, without the evidence of superposition, be accepted with caution.

An Eocene Travertine. In connection with the Lower Eocenes I would again briefly allude to the Travertine of Sézanne, in Champagne, which is of early Eocene (Palæocene of Saporta) age. This very remarkable deposit from a fresh-water spring formed not only around plants, which, as they decayed away, left their moulds in the travertine, but also encased a multitude of other objects. By injecting the moulds they have left with liquid plaster-of-Paris, and then dissolving away the calcareous matrix by a weak acid, casts of the most delicate objects (flowers with stamina, insects, spiders, etc.) are obtained in the most wonderful perfection.

CHAPTER XXIII.

THE UPPER-EOCENE SERIES.

The two Divisions of the Eocene based on their Faunal Value. Local Structural Differences. The London Basin. The Bagshot Sands. Their Structure. Synchronism of the Middle Division, with the 'Bracklesham Sands' and 'Calcaire Grossier.' The Hampshire Basin. The Bracklesham Sands. Organic Remains. Bournemouth Flora. The Barton Clay. Alum Bay. Hordwell Cliff. Organic Remains. Foreign Equivalents of the Upper Eocene. France and Belgium. Other Continental Areas. Great Extent and Permanence of the Eocene Nummulitic Ocean. Necessity of taking only the larger Extra-European Divisions for Comparison.

The two Divisions of the Eocene based on their Faunal Value. There is little difference of opinion with respect to the groups of strata to be included in the Lower Eocene,—the divisional line, based on the facies of the fauna and the community of many species, being by general consent placed at the top of the London Clay[1]. But with respect to the overlying series, considerable difference of opinion has prevailed. Accepting for the present the assignment of the Fluvio-marine series to the Oligocene, the formations below the Headon beds have been variously grouped into (1) Middle Eocene, consisting of the Bracklesham Sands and Middle Bagshot; (2) Upper Eocene, consisting of the Barton Clay and Upper Bagshot; or (3) the two have been grouped together into Middle Eocene, and the Fluvio-marine series has been taken to represent the Upper Eocene; while the Upper Bagshot has been referred by some to the Bracklesham, and by others to the Barton beds.

Of the 543 species of Mollusca of the Bracklesham Sands, only 81, according to Etheridge, are London-Clay species, and of the other classes there are still fewer species in common; whereas of the 310 Barton species of Mollusca, 95 are Bracklesham species; so that while only about 11 per cent. are in common to the London Clay and the Bracklesham

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[1] With the exception of the alteration I have made in allocating the Lower Bagshot to the London group.

Sands, the number of species common to the Bracklesham Sands and the Barton Clay amounts to about 30 per cent.[1]

While there is, therefore, a well-marked and definite line between the London Clay and the Bracklesham Sands,—corresponding, possibly, with some minor continental physiographical changes,—the palæontological break between the Bracklesham and Barton beds is comparatively slight. Consequently the more natural classification will be to unite these two formations into one division as under:—

	London Basin.	*Hampshire Basin.*
Upper Eocene	Wanting?	Barton Clay and Sands, 300 feet.
	Upper Bagshot, 200 feet Middle Bagshot, 50 feet	Bracklesham Sands, 600 feet.

This agrees with A. D'Orbigny's divisions of the Eocene into Suessonian (London group) and Parisian (Bracklesham and Barton) divisions in the Paris Basin.

Local Structural Differences. The Lower-Tertiary sands and clays, described in the last chapter, have many characters in common over the London, Hampshire, Belgian, and Paris Basins; and in the first three basins the London Clay presents similar argillaceous characters. The Formations we have now to consider present much greater structural differences in these several Tertiary districts—differences which give distinctive local characters to each. Even in the adjacent London and Hampshire Basins the differences are so great that the exact divisional lines are not yet defined with absolute certainty. In consequence it will be best to take each district separately.

THE LONDON BASIN.

The Bagshot Sands. The Bagshot Sands, including the two divisions, form a tract of poor and sterile lands, very pleasant in their open breezy heaths and tracts of pine woods, extending westward from Weybridge, past Woking and Bagshot, to Aldershot and Sandhurst; and again from Silchester to the neighbourhood of Newbury[2]. It might at first sight be supposed that there were neither fossils nor divisional lines in this great mass of apparently unproductive sands, but a closer examination shows that they are divided into an upper and lower series, separated by from 40 to 50 feet of laminated purple clays, green sands, and pebble-beds, in which middle series a few fossils are found.

[1] Etheridge in his 'Manual,' p. 620, gives 88 per cent.—evidently intended for 28 per cent.

[2] For information on the Bagshot district see various papers by the Rev. A. Irving in 'Quart. Journ. Geol. Soc.,' and 'Geol. Mag.'; and a paper of Prof. Rupert Jones in 'Proceed. Geol. Assoc.' for May, 1880.

The Lower-Bagshot Sands we have (for reasons before given) transferred to the division of the Lower Eocene. The correlation of the Upper sands still remains uncertain. When the Frimley railway-cutting was made, I found a few ferruginous casts of an undeterminable Nummulite, together with *Calyptræa*, *Natica*, *Cardium*, *Ostrea*, *Turritella*, seemingly referable to Bracklesham species; but more lately Mr. Herries and Mr. Monckton[1] found in another railway-cutting, near Pirbright, casts referred by them to

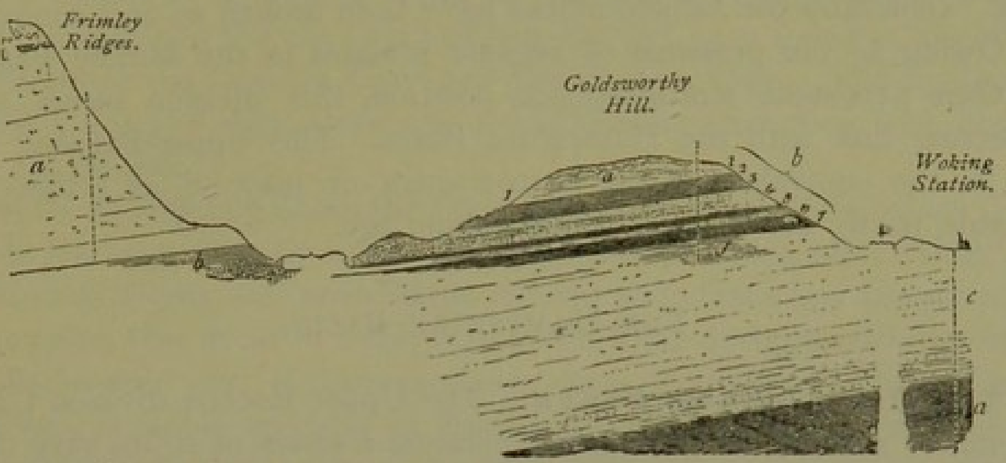

FIG. 182. Diagram-section of the Bagshot Sands, Woking. (From 'Quart. Journ. Geol. Soc.' vol. iii. p. 382.)
a. Upper-Bagshot Sands, 150 feet thick. *b. Middle Bagshots*, 45 feet, *with Turritella, Venericardia, Teeth of Fishes*, etc., in bed No. 4. *Traces of Vegetable impressions* in bed No. 7. *c. Lower-Bagshot Sands or Upper London-Clay beds*, 130 feet. *d. London Clay*, 400 feet.

Rostellaria rimosa, *Ostrea flabellula*, *Lucina mitis*, and *Tellina scalaroides*, which lead them to think that these sands may be the equivalent of the Barton Clay. Better preserved and more characteristic specimens are however needed, before the exact parallelism to these beds can be established.

The thin central glauconiferous sands contain a group of better preserved fossils, belonging to species which, though not numerous, are very characteristic. They have been found in railway-cuttings at Woking, Shapply, and Ascot. The most common of these fossils are :—

Ostrea flabellula, *Lam.*	Carcharodon angustidens, *Ag.*
Turritella sulcifera, *Lam.*	Pristis Hastingsiæ, *Ag.*
Corbula gallica, *Lam.*	Edaphodon Bucklandi, *Ag.*
Nummulites lævigatus, *Lam.* Fig. 184, *a*, *b*.	Myliobatis Dixoni, *Ag.*

I also found casts of the *Cardita planicosta* abundant in a seam of green sand in a shallow road-side cutting on Chobham Common, between Chobham and Ascot; also at Hawley Pond, west of Blackwater. The species in general are so characteristic of the Bracklesham Sands and lower part of the 'Calcaire Grossier,' that there can be little doubt of the correlation of these beds. It is this central band of green sands and foliated clays that holds up the water in the Blackwater Valley, and throws out

[1] 'Geol. Mag.' for 1881, p. 171; and 'Quart. Journ. Geol. Soc.,' vol. xxxix.

numerous small springs (many of them chalybeate) on the flanks of the hills where it crops out.

In the Bagshot Sands, as in the Woolwich Sands, blocks of concretionary sandstone, some of a very large size, are often met with; but they are rarely or never so compact and hard as those from the Lower-Tertiary beds. These blocks are found by probing the sands with iron rods on the Frimley, Chobham, and other high ridges of the Upper Bagshots. Generally the surface-blocks have been broken up and removed.

Owing to the presence of organic remains in the Middle Bagshots, and their persistent stratigraphical position, this division serves as the connecting link with the Hampshire Basin. The Upper-Bagshot Sands may be the equivalent of the Barton series, or may be, as I think more probable, partly or wholly of Bracklesham age.

THE HAMPSHIRE BASIN.

The Bracklesham Sands. The Upper-Eocene division ('Middle Eocene' of authors) of Hampshire presents a series of strata very distinct from those of the London Basin. In this district the fine coast-sections expose a nearly complete succession of the whole of the Eocene strata: (1) in the cliffs at Whitecliff Bay; (2) the cliffs at Alum Bay; and (3) the cliffs between Barton and Poole Harbour. The Upper-Eocene strata present great variations,—glauconiferous sands, chocolate-coloured laminated clays, and marls predominating at Whitecliff; bright-coloured yellow and red sands and argillites, carbonaceous and grey clays, and lignite bands in Alum Bay; and fine light-coloured sands with a few subordinate clay beds, and fawn-coloured foliated sandy clays, in the Bournemouth district. The division consists of two groups, (1) the Bracklesham Sands, and (2) the Barton Clay (see section, Fig. 189).

On the flat coast extending from Selsea Bill, near Bognor, westward to beyond Bracklesham Farm, there may also be seen at low tide, and after certain winds which remove the covering of sand and shingle, a series of strata cropping out at various angles, and extending for a distance of about two miles along the shore. These strata consist, according to the Rev. O. Fisher[1], of a series of sandy grey and laminated liver-coloured clays, dark-green sands, and compact shelly sands. Many of the beds are very fossiliferous. Messrs. Edwards and Searles Wood have described about 460 species of Mollusca from this locality alone. The relation of these beds to other members of the Tertiary series cannot, however, here be seen. It is only known that they rise and are lost before reaching Hayling Island, where the London Clay comes to the surface.

[1] 'Quart. Journ. Geol. Soc.,' vol. xviii. p. 65.

The Eocene strata are again well exposed on the north-eastern point of the Isle of Wight at Whitecliff Bay. They are there in a vertical position, and comprise the whole of the Eocene series from the Reading beds to the top of the Bembridge beds. The central strata are very similar to those at Bracklesham, though not so fossiliferous; nor are the fossils so well preserved. As these strata range further westward, their fauna gradually disappears, so that at Alum Bay, where again the whole of the Eocene series is exhibited without a break in the fine cliff-section, not a fossil, except the plants of the one thin leaf-bed, has yet been found in any of the strata between the London Clay and the Barton Clay. The brilliantly-coloured sands and dark clays are unfossiliferous, excepting that beds of lignite are present.

On the Hampshire coast, the same beds range from Hengistbury Head to Poole Harbour, forming an exceedingly variable series, more sandy than in the Isle of Wight, and remarkable for the abundance and beauty of the plant remains that occur in a few seams. In some dark glauciferous sands, about half-a-mile east of Bournemouth, casts of Ostrea, Tellina, Phorus, Natica, etc., probably referable to Bracklesham species, have also been discovered. In their general aspect, the light-coloured sands and the extensive heaths of the Christchurch and Bournemouth districts much resemble those of the Bagshot Sands in the London Basin; and there is in Hampshire, as in Surrey, owing to the extreme rarity of fossils, the same difficulty in establishing any exact stratigraphical divisions.

Organic Remains. The special localisation and abundance of the fossils in the beds at Bracklesham Bay, Stubbington, Netley, Southampton, and Lyndhurst, and their scarcity in the Bournemouth district, are features to be noticed.

Foraminifera are extremely abundant at some places. One sandy clay-bed at Bracklesham is crowded with *Nummulites variolarius*, Sby., *Alveolina sabulosa*, Mont., *Miliola communis*, Desh., *Biloculina ringens*, Lam., and *Discorbina trochidiformis*, Lam., and is represented in the Mixen Rocks by a sandy mass of *Aveolinæ* and *Miliolæ*. *Nummulites lævigatus*, Lam. (Fig. 184, *a*), also abounds in another bed lower in the same series[1].

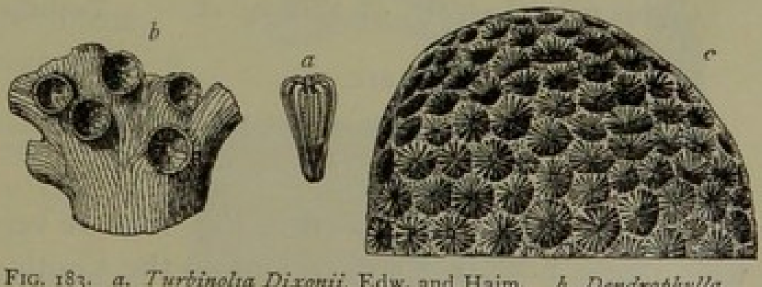

FIG. 183. *a. Turbinolia Dixonii*, Edw. and Haim. *b. Dendrophylla dendrophylloides*, Lonsd. *c. Litharæa Websteri*, Bow.

Corals, as might be expected from the nature of the sea-bed, are more common than in the London Clay. Still they are not abundant: eighteen species have been described. They are mostly

[1] For a full list of the Foraminifera see Dixon's 'Sussex,' 2nd edit., by Professor Rupert Jones, p. 168.

deep-sea Corals, such, however, as would not, according to Professor Duncan, indicate a depth of water exceeding 100 fathoms, and a sandy or oozy bottom; and he considers the few reef-builders only stragglers from the great reefs of the Nummulitic seas of Southern Europe. The more characteristic species are,—

Turbinolia Dixoni, *Lam.* Fig. 183, *a.*
Oculina incrustans, *Dunc.*
Paracyathus crassus, *Edw. and Haime.*
Diplohelia papillosa, *Edw. and Haime.*
Dendrophylla dendrophylloides, *Lonsd.* Fig. 183, *b.*
Litharæa Websteri, *Bow.* Fig. 183, *c.*

Echinodermata are very scarce, the best known being *Echinopsis Edwardsii*, Forb., Pl. XV, fig. 8. Of the *Crustacea* only a few imperfect specimens of Macroura have been found, but small Ostracoda are abundant, such as *Cythere plicata*, Münst., *C. horrescens*, Jones, *Cytherella compressa*, Münst., and others.

Polyzoa are numerous, affixed generally to shells and pebbles. Amongst them are *Lunulites urceolata*, Lam., *Idmonea coronopus*, Defr.

No *Brachiopoda* are known to occur.

Mollusca. In this class of fossils, the Bracklesham beds are the richest of the English Tertiaries, the number of known species[1] amounting to 543.

Of the *Bivalve shells*, the most abundant are,—

Arca biangula, *Lam.*
Cardita planicosta, *Lam.* Fig. 184, *e.*
Cardium porulosum, *Brand.*
Chama sulcata, *Desh.*
Corbula striata, *Lam.* Pl. XIV, fig. 15.
Crassatella sulcata, *Sol.* Pl. XIII, fig. 25.
Cytherea trigonula, *Desh.*
Lucina saxorum, *Lam.*
Neæra argentea, *Desh.*
Ostrea flabellula, *Lam.*
Pecten corneus, *Sby.*
Pectunculus pulvinatus, *Lam.*

And of the Univalves—

Bifrontia Laudinensis, *Lam.* Pl. XIII, fig. 6.
Buccinum stromboides, *Lam.*
Cassidaria coronata, *Brand.* Pl. XIII, fig. 2.
Cerithium giganteum, *Lam.* Fig. 184, *g.*
Conus deperditus, *Brug.* Pl. XIII, fig. 3.
Cypræa tuberculosa, *Sby.* Pl. XIII, fig. 18.
Fasciolaria uniplicata, *Lam.* Pl. XIII, fig. 7.
Hipponyx cornucopia, *Lam.* Pl. XIII, fig. 10.
Phorus agglutinans, *Lam.* Pl. XIII, fig. 14.
Pyrula nexilis, *Lam.*
Voluta spinosa, *Sby.*
Turritella terebellata, *Lam.*

The Cephalopods are,—

Beloptera belemnitoidea, *Blainv.* Pl. XV. fig. 2.
Belosepia Cuvieri, *Voltz.* Pl. XV. fig. 1.
Nautilus imperialis, *Sby.*

The few fossils included in Fig. 184 are very characteristic, and have a wide range, both in England and on the Continent, and some even beyond.

Teleostean Fishes are not so numerous as at Sheppey, but in palatal remains of Myliobatis, Ætobatis, and Edaphodon, the Bracklesham Sands

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[1] They have been described by Mr. Frederick Edwards and Mr. Searles Wood in the 'Monogr. Palæont. Soc.' from 1848 to 1877.

are rich. With these Rays and Chimæroid fishes, there are also found the

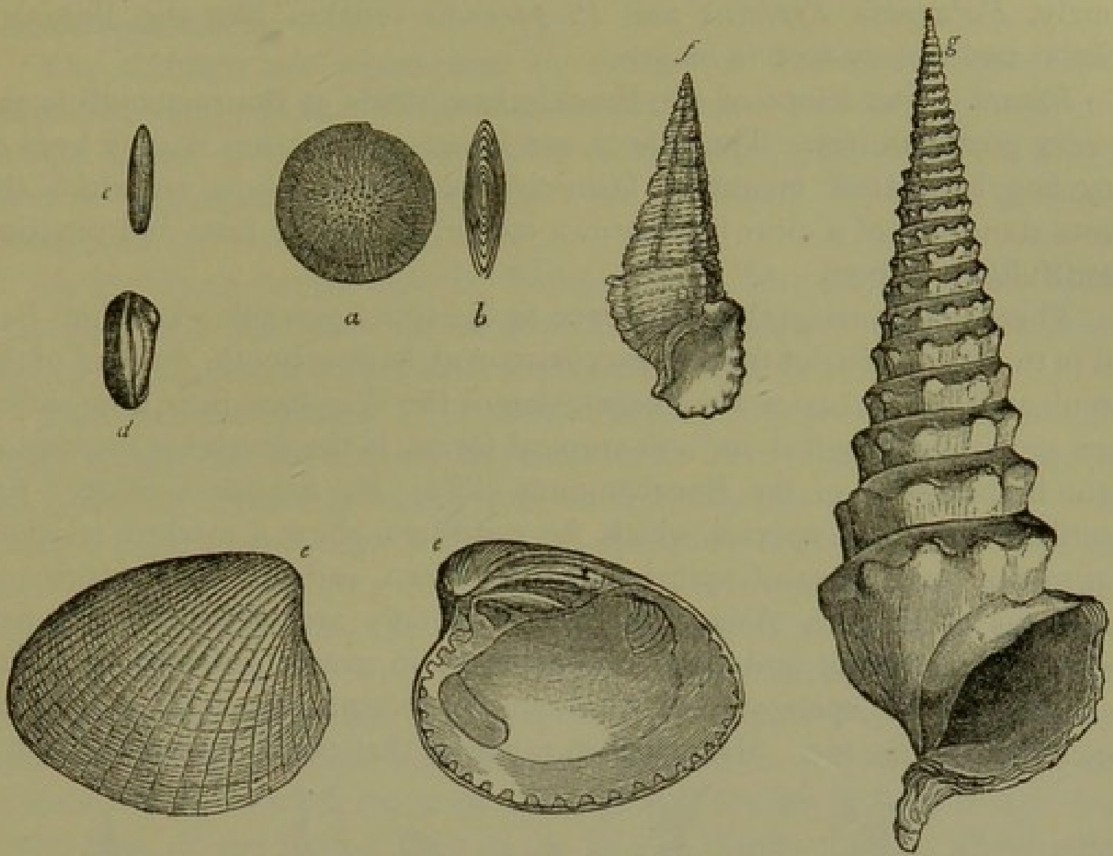

FIG. 184. Fossils of the Bracklesham Sands.
a, b. Nummulites lævigatus, Lam., nat. size. *c. Alveolina Boscii*, Féruss. × 2. *d. Cythere plicata*, Münst. $\frac{12}{1}$. *e. Cardita planicosta*, Lam., $\frac{1}{2}$. *f. Cerithium hexagonum*, Lam. *g. Cerithium giganteum*, Lam., $\frac{1}{4}$.

remains of the Saw-fish (*Pristis*) and of various Sharks; altogether twenty-nine species, of which the most abundant are,—

Myliobatis Dixoni and M. Toliapicus, *Ag.*	Lamna elegans, *Ag.* Fig. 185, *c.*
Ætobatis irregularis, *Ag.*	Otodus lanceolatus, *Dixon.*
Carcharodon heterodon, *Ag.*	Elasmodus Hunteri, *Egerton.*
Edaphodon Bucklandi, *Buckl.*	Galeocerdo latidens, *Ag.* Fig. 185, *a.*

Some of the Rays must have been enormous fishes. Mr. Dixon had a dental plate of *Ætobatis subarcuatus* in his collection which measured four inches in width. Rare specimens of the defensive dorsal spines of a *Silurus* have been found; and the peculiar nasal defensive bone of a fish of the Xiphioid family (*Cœlorhynchus*) are not uncommon.

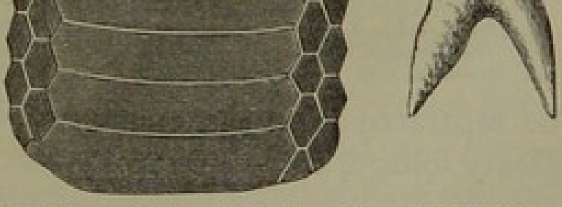

FIG. 185. *a. Galeocerdio latidens*, Ag. *b. Myliobatis Toliapicus*, Ag. *c. Lamna elegans*, Ag.

Reptiles. Crocodilian remains are rare at Bracklesham. Mr. Dixon mentions only the Gavial; nor are Chelonian remains much more common; four species are recorded. The most interesting of the Reptilian remains are the Ophidians of which the vertebræ are not uncommon. Two species have been determined by Owen, namely, *Palæophis Typhæus* and *P. porcatus*—snakes like the Boa-constrictor, and twenty feet in length.

Plants. The Flora of the Bracklesham sands at Bournemouth is one of very great interest. The plants are found, as at Alum Bay, in beds of very fine, laminated, cream or fawn-coloured, sandy clays, on which the plants stand out of a clear light-brown colour, with their form and venation beautifully preserved.

There is a considerable difference in the types prevailing at Alum Bay and in the Poole district from those common at Bournemouth. Instead of the abundant Palm and poor Fern vegetation of the Wareham beds, a luxuriant Fern growth, of tropical and sub-tropical forms, is the dominant vegetation in the higher beds of the Bournemouth cliffs. Mr. Starkie Gardner[1] has described seventeen species which, he considers, show a marked relationship to the present sub-tropical American Flora, and in a lesser degree to the Ferns of Eastern Asia and Java; two only are of European types. Species of Osmunda and Chrysodium occur in great profusion, and with these are found species of Lygodium, Podoloma, Anemia, Adiantum, Gleichenia, Pteris, etc. Mr. Gardner remarks that one Chrysodium cannot

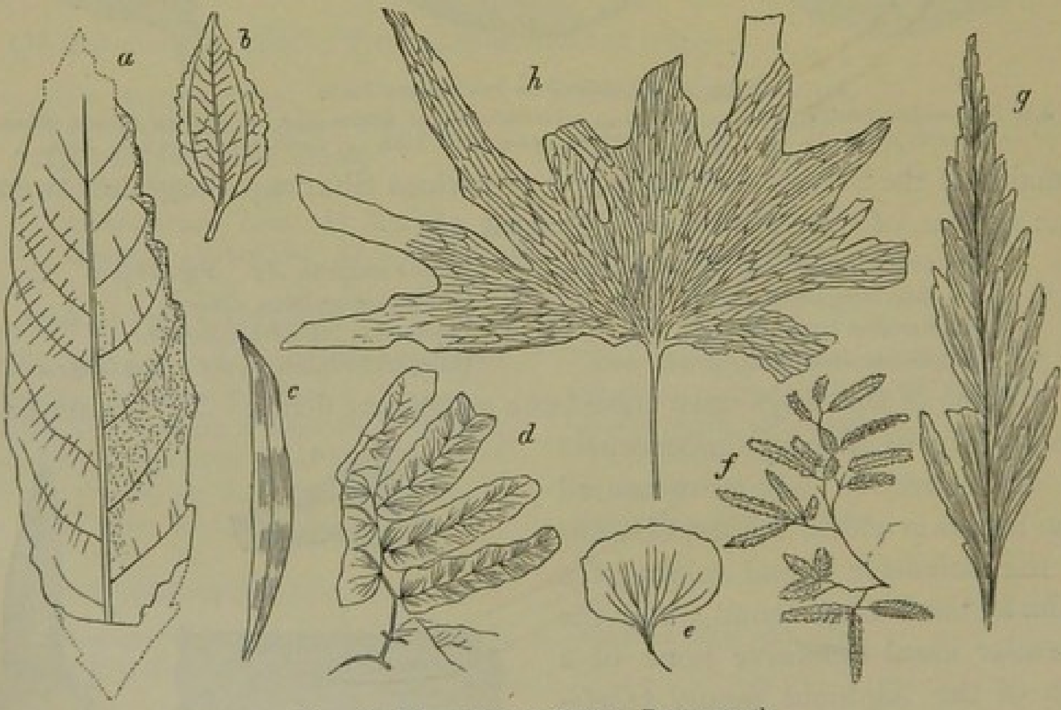

FIG. 186. Upper-Eocene Plants; Bournemouth.
a. Dryandroides hakeæfolia, Ung. *b. Zizyphus Ungeri*, Etting. *c. Podocarpus Eocænicus*, Ung. *d. Gleichenia Hantonensis*, Wank. *e. Adiantum apalophyllum*, Sap. *f. Lygodium Kaufussi*, Heer. *g. Anemia subcretacea*, Sap. *h. Hewardia regia*, Etting. and Gard.

be separated from the existing *C. aureum*, a magnificent plant, with dark glossy foliage, abundant in Bermuda; whilst one Osmunda is completely

[1] 'Palæontographical Society's Monographs,' 1879-84, xxxviii. p. 1, &c., and 'Quart. Journ. Geol. Soc.,' vol. xxxv. p. 299, &c.

identical with the existing *O. javanica*, which now inhabits the tropics in the Eastern hemisphere.

The Conifers are represented by species of Cupressus, Podocarpus, Taxodium, and Sequoia. With these are associated some large pinnate and palmate leaves of Palms, and remains of Aroids, together with, in places, leaves of angiospermous forest-trees such as Beech, Willow, Fig, Eucalyptus, etc.

In the same series, east of Bournemouth, Mr. Gardner has found in another bed the fruits and seeds of such Sheppey genera as *Nipa, Hightea, Apeibopsis*, together with fragments of Conifers.

The Barton Clays. The Barton beds, which are the highest of the Eocene formations, have a very limited range. At High Cliff, near Barton, they consist of 15 feet of sands, with an irregular seam of grey clay containing a profusion of small marine and estuarine shells, and of about 350 feet of stiff brown and grey clays with lines of septaria and a large number of fossils. At Alum Bay the upper bed consists of pure white quartzose sand, without fossils, 120 feet thick; and the lower of dark grey and glauconiferous clays, about 300 feet thick; while at Whitecliff Bay the sands have expanded to 200 feet, are argillaceous, and contain fragile casts and impressions of shells, with the underlying clays reduced to about 250 feet. At the base of the Barton Clay in the Isle of Wight there is a bed a few inches thick of rolled flint pebbles; in the cliff west of Hengistbury Head this seam expands to the thickness of 10 to 12 feet, forming at its outcrop, between there and Bournemouth, a thick shingle-bed like that at the base of the London Clay in parts of the London Basin.

At Barton **the organic remains** are numerous and well preserved; they are less so at Alum Bay and Whitecliff Bay. The Barton Clay contains 310 species of *Mollusca*, amongst which those of the genera *Pleurotoma*, *Fusus*, and *Voluta* predominate, whilst Cephalopods are extremely scarce. Nautili have not yet been met with. The characteristic species are,—

Chama squamosa, *Brand.*
Corbula pisum, *Sby.*
Crassatella sulcata, *Sby.* Pl. XIII, fig. 25.
Limopsis scalaris, *Sby.* Pl. XIII, fig. 24.
Ancillaria buccinoides, *Lam.* Pl. XIII, fig. 1.
Cancellaria evulsa, *Brand.* Pl. XIII, fig. 5.
Conus scabriculus, *Sby.*
Marginella ovulata, *Lam.* Pl. XIII, fig. 8.
Mitra labratula, *Lam.* Pl. XIII, fig. 11.
Murex asper, *Brand.* Pl. XIII, fig. 12.
Oliva Branderi, *Sby.* Pl. XIII, fig. 13.
Rostellaria rimosa, *Sby.*
Strombus Bartonensis, *Sby.* Pl. XIII, fig. 15.
Terebellum sopitum, *Brand.* Pl. XIII, fig. 20.
Triton argutus, *Sby.* Pl. XIII, fig. 16.
Trochus monilifer, *Lam.*
Typhis pungens. Pl. XIII, fig. 17.
Voluta Solandri, *Edw.* Pl. XIII, fig. 9.

Individual *Corals* are not common, though twenty-eight species have been described, including *Turbinolia Bowerbanki*, Edw. and H., *Paracyathus crassus*, Edw. and H. The others are mostly Bracklesham species.

Ostracoda are common, especially *Cythere striatopunctata*, Roem., *C. plicata*, Münst., *Cytheridea Mülleri*; *C. perforata*, Roem.

The characteristic Foraminifera are *Nummulites variolarius* (Fig. 187, *g*, *h*), and *N. elegans*[1] (Fig. 187, *e*, *f*).

There are few *Echinodermata*, but they are characteristic, such as *Schizaster D'Urbani*, Forb. (Pl. XV, fig. 5), and *Eupatagus Hastingsiæ*, Forb. (Pl. XV, fig. 7).

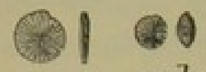

FIG. 187. *e, f. Nummulites elegans* (*N. Prestwichianus*, Jones) × 2. *g, h. Num. variolarius*, Lamarck × 2.

Fishes;—teeth of Lamna abound, and palatal teeth of Myliobatis are not rare.

French and Belgian Equivalents. Whereas the Lower Eocenes of the London Basin show, as before mentioned, so close a relation to the Belgian, and a more distant alliance with the French series, it is the reverse with the Upper Eocenes, the French series being palæntologically closely related to the Upper Eocene strata of the Hampshire Basin, and scarcely represented in the London Basin.

England (Hants).	*France* (Paris Basin).	*Belgium.*
Barton Clay and Sands	Calcaire de St. Ouen. Gres de Beauchamp or Sables Moyens.	Système Wemmelien. " Laekenien (part)?
Bracklesham Sands .	Caillasses. Calcaire Grossier. Glauconie Grossière.	Système Laekenien (part). " Bruxellien. " ? Panisellien.

The 'Calcaire Grossier' of the Paris Basin consists of a group of strata of much interest. At the base, glauconiferous sands and flint pebbles prevail, with, in places, a profusion of *Nummulites lævigatus*. A little

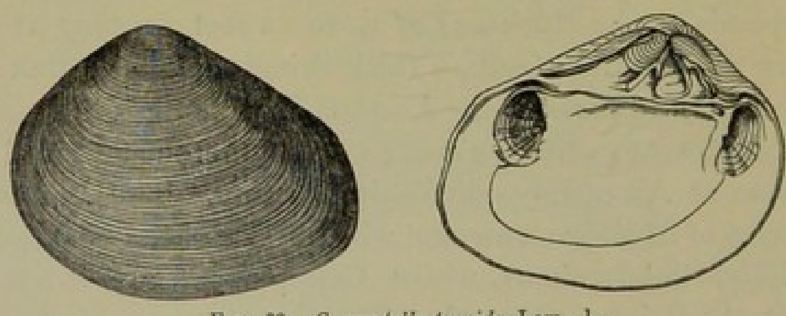
FIG. 188. *Crassatella tumida*, Lam., $\frac{1}{3}$.

higher are the light-coloured calcareous sands and friable freestones of Grignon near Versailles, Parnes near Chaumont, and Damery near Epernay, which abound with shells in a remarkable state of preservation,—with many the colour only wanting. Amongst these are the typical *Cerithium giganteum*, *Cardita planicosta*, *Crassatella tumida*, *Pectunculus pulvinatus*, *Turritella imbricataria*, *Voluta spinosa*, *V. cithara*, etc.[2] Specimens of a fine bivalve—the *Crassitella tumida* (Fig. 188),—not found in England, and

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[1] Professor Rupert Jones identifies this with the *N. Wemmelensis* of the Brussels Basin.

[2] For the Molluscan fauna of this rich fossiliferous Formation, and of the other members of the Tertiary series of the Paris Basin, the student should consult the two great works of Deshayes, 'Description des Coquilles Fossiles des Environs de Paris,' and 'Description des Animaux sans Vertèbres decouverts dans le Bassin de Paris'; and for Belgium, Nyst's 'Description des Coquilles et des Polypiers fossiles des Terrains Tertiaires de la Belgique.'

of *Cerithium giganteum*, sometimes a foot or more in length, are extremely common in the lower part of the Calcaire Grossier in many parts of the Paris Basin, especially in Champagne.

The higher part of the Calcaire Grossier consists of calcareous freestones, which supply the fine building-stones of Paris: the lower of these beds are characterised by the abundance of *Orbitolites complanata* and Triloculinæ (*banc à Miliolites*), and the upper by numerous species of *Cerithium*. These are capped by magnesian marls and siliceous limestones (Caillasses), containing *Cerithium lapidum*, *Planorbis Chertieri*, *Limnæa Michelini*, and other estuarine and fresh-water fossils.

To these succeed fossiliferous sands and sandstones (Sables Moyens), typical at Beauchamp and at Augers (Oise), with some Corals, numerous Nummulites (*N. variolarius*), and a great variety of Molluscs, including *Corbula gallica*, *Cytherea elegans*, *Lucina saxorum*, *Turritella sulcifera*, *Melania hordacea*, *Cerithium mixtum*, etc.

In Belgium the subdivisions are more frequent, and the limitation of species less definite. The Bruxellian and Laekenian have been divided into five zones;—the lowest characterised by the *Rostellaria ampla* (?), *Pectunculus pulvinatus*, *Cardium porulosum*, etc.; the second by *Nummulites lævigatus*, *Cardita planicosta*, and *Ostrea cymbula*; the third and fourth by *Ditrupa strangulata*, *Pecten corneus*, *Corbula gallica*, *Nummulites variolarius*; and the fifth by *Pecten corneus*. To these succeed the buff-coloured sands and ferruginous sandstones termed by MM. Rutot and Vincent the 'Wemmelian System,' with *Nummulites Wemmelensis*, *N. variolarius*, *Cardita sulcata*, etc. This by some of the Belgian geologists is the only stage corresponding to the Barton beds; whilst others include the fourth and fifth stages here referred to the Bruxellian.

Other Continental Equivalents. Whilst it is a question how far the Lower Eocene extends southwards, the Upper Eocene, with the characteristic *Ceritheum giganteum* and *Cardita planicosta*, has a wider and well-defined southern range. Strata of this age with numerous fossils occur in the Cotentin (Normandy); again in Brittany; and further south, at Blaye, near Bordeaux, where they consist of a freestone like that of Paris, with Nummulitic Sands at the base. They extend also irregularly through the southern departments of France—Aude, Hérault, and the Rhone, to Nice and Switzerland, and eastward into Bavaria. Further southward the several divisions of the Upper Eocene, with probably the upper division of the Lower Eocene (Suessonian), merge into the grand series of 'Nummulitic strata' (with *N. planulatus*, *N. lævigatus*, *N. scaber*, *N. variolarius*, *N. complanatus*, *N. Puschi*, *N. Biaritzensis*—many thousands of feet thick—which stretch through Southern Europe, Asia Minor, North Africa, Egypt, and Persia into India and China.

Occupying the sites where now the great mountain-ranges of the

Pyrenees, the Alps, the Apennines, the Carpathians, and other high chains rear their crests, and spreading also over the present Mediterranean area, a deep and wide Ocean extended from the South-Western European area to the further extremity of South-Eastern Asia ; and from it branched shallow seas, stretching irregularly northward into France to Belgium, and forming the deep bay of the Bracklesham area with a branch penetrating as far as the Bagshot district. The ocean swarmed with Foraminifers, while there were but comparatively few Molluscs, which, on the other hand, flourished in the northern fringing bays and gulfs. In this one large, common, and deep oceanic trough, the thick and continuous nummulitic strata were gradually accumulated ; in the other more independent areas a more varied, thinner, and irregular series of deposits were localised. Everywhere in this wide-spread sedimentation geological time is marked by the successive zones of Nummulites. Thus, in our western region, the lower division was characterised by the presence of the *N. planulatus*, the lower subdivision of the Upper Eocene by *N. lævigatus*, and the upper subdivision by *N. variolarius*. Further eastward, representative forms of stronger growth, with many other species of subordinate importance, swell the numbers and add to the definiteness of each special zone.

Extra-European Eocene Strata. While in the European area a long interval elapsed between the close of the Cretaceous period and the insetting of Tertiary strata, of which lapse of time no life-records are preserved, there were more distant areas in which the record was not broken and where the continuity of life was preserved. In India, the connection was partially maintained, and in New Zealand there would appear to have been no break, and the sequence from the Mesozoic to the Cainozoic series seems to be uninterrupted. It is the same in the Western States of North America, so much so that the position of the Laramie group was long a subject of discussion. To this allusion has already been made at the end of Chapter XIX. It will, however, be desirable to postpone the further consideration of the more distant Tertiary equivalents until we have described both the Eocene and Oligocene of Europe ; for in other parts of the world, where the same subdivisions do not hold, we can only take larger groups, such as those formed by the several lower or older Tertiary Formations, and by the upper Tertiaries which comprise the Miocene and Pliocene. The Tertiary series in those countries may admit of as many divisions as in Europe, but it is not at present possible to establish the contemporaneity of the lesser subdivisions, though the larger divisions are sufficiently defined.

CHAPTER XXIV.

OLIGOCENE PERIOD (UPPER EOCENE OF *FORBES*).

FLUVIO-MARINE SERIES OF THE ISLE OF WIGHT.

USE OF THE TERM. PHYSIOGRAPHICAL CHANGES. EXTENT AND DIVISIONS OF THE OLIGOCENE IN ENGLAND. THE HEADON SERIES: ITS SUBDIVISIONS: ORGANIC REMAINS: FLUVIO-MARINE ORIGIN. THE BROCKENHURST BEDS: THEIR RELATION TO THE LOWER OLIGOCENE. THE OSBORNE SERIES. THE BEMBRIDGE SERIES. FRESH-WATER AND LAND REMAINS. IMPORTANCE OF THE MAMMALIA. TORTOISE EGGS. THE HEMPSTEAD SERIES. FRESH-WATER AND MARINE STRATA. PLANTS. THE BOVEY-TRACEY DEPOSIT: ITS FLORA. THE ANALOGOUS FLORA OF MULL AND ANTRIM. ABSENCE OF MIOCENE STRATA. RELATION TO THE STRATA OF THE PARIS BASIN AND OF BELGIUM. THE OLIGOCENE BEDS OF GERMANY AND THE REST OF EUROPE. CHARACTER OF THE PERIOD. PROLONGED CONTINENTAL MOVEMENTS. FOREIGN EQUIVALENTS. BELGIUM. FRANCE: THE PARIS BASIN: THE SOUTHERN PROVINCES. SWITZERLAND. GERMANY. AUSTRIA. THE OLDER EXTRA-EUROPEAN TERTIARIES. WESTERN ASIA. EXTRA-PENINSULAR INDIA; PENINSULAR INDIA. AUSTRALIA. NEW ZEALAND. NORTH AMERICA.

The Use of the Term. Whether the term Upper Eocene, Lower Miocene, or Oligocene be used to denote a certain stage in the Tertiary series, its value being only classificatory, is a matter of secondary importance; yet with the progress of the science and the multiplication of the geological horizons, it becomes convenient to re-arrange the groups for purposes of generalisation and definition from time to time.

In this country, where the Oligocene strata have so limited a development, there may scarcely seem to be sufficient reason for separating the Fluvio-marine series of the Isle of Wight from the underlying Eocene formations. The land and fresh-water Mollusca afford no terms of comparison with the fossils of the lower groups; and the marine Mollusca are, with the exception of the Brockenhurst beds, very limited in their number, and there are many in common. The fauna of the Hempstead beds, though smaller, is more special. Barton species, however, still continue to appear to the top of the series, though they gradually become fewer.

On the Continent, where there is a large marine Molluscan fauna of some 800 to 1000 species, its distinctiveness is more apparent: a large number of species are peculiar to this series, and the general facies of the fauna is perhaps equally as well marked as that of the Eocene.

But more important than this is the Mammalian fauna with its numerous and typical Pachyderms, combined, as pointed out by Gaudry, with the presence of Ruminants of a peculiar type without horns, and of Carnivora still retaining some Marsupial characters, whilst there is an absence of other important orders, such as the Proboscideans.

Equally important are the physical features of the time. It was a period of slow continental movements, which destroyed the old Eocene landmarks, and preceded the greater and more abrupt disturbances that accompanied the elevation of several of the great mountain-ranges of Europe (the principal chain of the Alps and others). Extensive tracts of land in Central Europe were converted into lakes and lagoons; other districts were submerged and covered by marine deposits, whilst some sea-areas were raised and converted into deltas. These are causes which affected both the fauna and flora, and impressed on them, as on the physiography of the Oligocene period, a character and an individuality which certainly seem to entitle it to the separate position in the Tertiary series given to it by Beyrich.

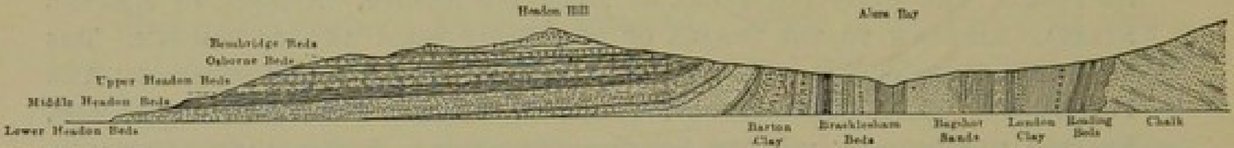

Fig. 189. Section of Headon Hill and Alum Bay. (Reduced from Mr. Bristow's section in Mem. Geol. Survey.)

Extent and Divisions of the Oligocene in England. In the Hampshire Basin the Bracklesham and Barton beds are succeeded by a series of Fluvio-marine strata; that is to say, a series of alternating fresh-water and brackish-water beds, with subordinate marine strata, of a character very distinct from that of any of the underlying groups, and presenting a very close analogy with similar deposits of the Paris and Belgian Basins. These beds in England are confined to the Isle of Wight and Hampshire coast.

The succession of these strata to those of the preceding marine Eocenes is exhibited very clearly in the cliffs ranging from Alum Bay to Sconce Point in the Isle of Wight, and again in those of Whitecliff Bay and Bembridge at the other end of the Island. They also form the cliffs which extend from Barton, near Christchurch, to Milford, near Lymington.

This fluvio-marine series is divided into four groups, namely, (1) the Hempstead Beds, (2) Bembridge series, (3) Osborne or St. Helen's Beds; (4) Headon Hill Beds[1].

[1] For the geology of the Isle of Wight, and the correlation of the strata with those of the Paris Basin, the reader should consult the several papers by Professor E. Forbes and Mr. Bristow in the 'Memoirs of the Geological Survey' for 1856 and 1862; and papers in the 'Quart. Journ. Geol. Society,' by Fisher, Wright, Judd, Tawney, Keeping, Gardner, the author, and others.

It is a question, however, whether the Osborne division need be retained. There are no fossils peculiar to it. The majority are those of the Bembridge series, of which it may be considered the lower stage. These several deposits were formerly, and are still by some geologists, designated the Upper Eocene; but others adopt the continental classification, and apply the term Oligocene to the whole of this series, the divisions of which are as under:—

		Maximum thickness.
Upper Oligocene	*Wanting.*	. . . . .
Middle Oligocene	Hempstead Beds	160 feet.
Lower Oligocene	Bembridge and Osborne Beds	240 "
	Headon and Brockenhurst Beds	180 "

The Headon Beds are subdivided into,—1. Upper (estuarine and fresh-water); 2. Middle (marine); 3. Lower (estuarine and fresh-water). At the north end of Alum Bay the fine white sands of the Barton group are succeeded conformably by a series of thin, fossiliferous, green, and white marls, and brown, grey, and red clays, with which are intercalated thick, soft, earthy, fresh-water limestones,—forming the lower part, while the Bembridge beds form the upper part, of Headon Hill, which rises to the height of 397 feet, and is capped by 12 to 15 feet of gravel (Fig. 189). The marls and limestones of the lower subdivisions of the Headon series are laden with land and fresh-water shells, seeds of Chara, etc. The most common and characteristic species are,—

Limnæa longiscata, *Desh.* Fig. 191, *g.*
" pyramidalis, *Sby.* Fig. 190, *a.*
Planorbis euomphalus, *Sby.* Fig. 190, *f.*
" lens, *Brong.* Fig. 190, *h.*
Paludina lenta, *Sby.*
Melanopsis carinata, *Sby.* Fig. 190, *i.*
Neritina aperta, *Sby.*, Pl. XIV, fig. 2.
Helix Headonensis, *Edw.*
Cyrena cycladiformis, *Desh.*
Potamomya plana, *Sby.*
Unio Solandri, *Sby.*
Chara Wrightii, *Forb.*

To these succeed a few feet of brackish-water and marine marls and clays, containing,—

Cytherea incrassata, *Desh.* Pl. XIV, fig. 8.
Nucula deltoidea, *Phil.*
Ostrea velata, *S. Wood.* Pl. XIV, fig. 10.
Buccinum labiatum, *Sby.*
Cerithium ventricosum, *Sby.*
" cinctum, *Sby.*
Neritina concava, *Sby.*
Murex sexdentatus, *Sby.* Pl. XIV, fig. 3.

The marls and clays forming, with the thick beds of soft light-coloured limestones, the upper subdivision of the Headon series, abound in Limnæa, Cyrena, Planorbis, Cerithium, and Potamomya. A noticeable feature of this portion of the series is the rapid thinning-out of the limestones, which are ten or twelve feet thick at Headon Hill, but as they range northward to Colwell Bay are reduced to four or five feet. They are altogether wanting at Whitecliff Bay.

At the same time that these fresh-water limestones thin out, the marine bed, with the Ostrea, Nucula, Cytherea, etc. of Headon Hill, becomes thicker and more fossiliferous. At Colwell Bay it contains some twenty or more marine species, of which the *Ostrea velata* and *Cytherea incrassata* form a matted mass or bank *in sitû*. At Whitecliff Bay the marine species in

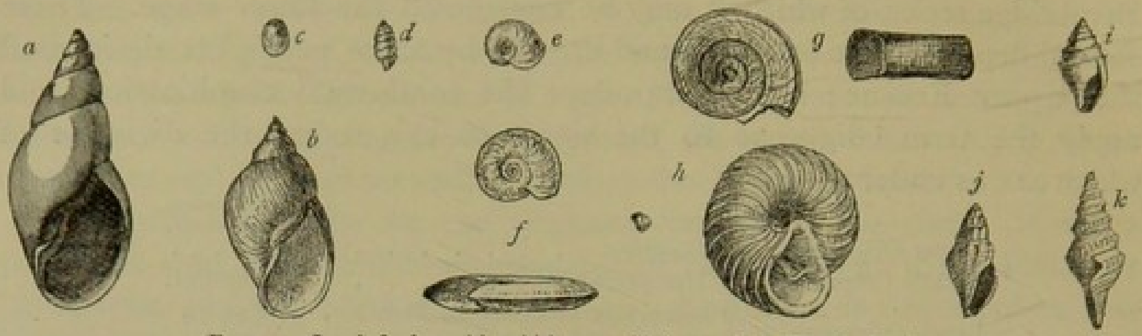

FIG. 190. Land, fresh- and brackish-water Mollusca of the Headon Series.
a. Limnæa pyramidalis, Desh. *b. Limnæa fabulum*, Brong. *c. Velletia elegans*, Sby. *d. Pupa oryza*, Edw. *e. Planorbis platysoma*, S. Wood. *f. Planorbis lens*, Brong. *g. Planorbis euomphalus*, Sby. *h. Helix labyrinthica*, Say (nat. size and enlarged). *i. Melanopsis carinata*, Sby. *j. Borsonia sulcata*, Edw. *k. Pleurotoma plebeia*, Sby.

this bed are still more numerous, but more difficult of determination, as they are mostly in the state of casts.

The Brockenhurst Beds. Passing over to the opposite coast, the marine beds are to be seen in the cliff-section between Milford and Hordle and in a pit near Lymington; whilst a few miles further inland they were found in their greatest development in the railway-cutting at Brockenhurst. They there contain the well-marked marine fauna that first led A. Von Koenen[1] to identify these beds with the Oligocene strata of the Continent. Of the fifty-six species then determined, he found forty-three belonging to the Lower Oligocene of Germany. The number has since been increased by Professor Judd to 187, of which he considers thirty-seven only to be Barton species. The Brockenhurst fossils are in an excellent state of preservation, and embedded in a light-coloured marl or clay exceeding thirty feet in thickness. The following are amongst the most common species of this zone:—

Cancellaria elongata, *Nyst.*
Cerithium pseudocinctum, *D'Orb.*
Conus procerus, *Beyr.* (C. alatus, *Edw.*).
Murex sexdentatus, *Sby.* Pl. XIV, fig. 3.
Natica labellata, *Lam.*
Nematura parvula, *Desh.*
Pleurotoma subdenticulata, *Goldf.* Pl. XIV, fig. 1.
Voluta suturalis, *Nyst.* (V. contabulata, *Edw.*).
,, decora, *Beyr.* (V. maga, *Edw.*).
Cardita paucicostata, *Sandb.*
,, deltoidea, *Sby.*
Cardium obliquum, *Lam.*
Clavagella Goldfussi, *Whil.*
Corbula cuspidata, *Sby.*
Cytherea incrassata, *Desh.* Pl. XIV, fig. 8.
Lucina concava, *Defr.*
Ostrea velata, *S. Wood.* Pl. XIV, fig. 10.
Trigonocœlia deltoidea, *Lam.* Pl. XIII, fig. 23.

Professor Duncan[2] has described thirteen species of Corals from this bed, forming a group closely corresponding with the group of Lower-Oligocene Corals of North Germany, and consisting chiefly of reef-building corals, with a species of Madrepora (*M. Anglica*, Dunc.) of great size, allied

[1] 'Quart. Journ. Geol. Society,' vol. xx. p. 97, 1864.
[2] 'British Association Report' for 1868.

to the *M. crassa* of the Pacific and southern Oceans. Amongst the other species are *Solenastræa cellulosa*, Dunc., and *Lobopsammia cariosa*, Goldf.

Professor Judd[1] differs, however, from the view generally held respecting the position of the Brockenhurst beds, being of opinion that they occupy a higher position in the series than the estuarine beds of Headon Hill; but although—owing to the sliding of the strata and the extensive talus which renders it difficult to follow them continuously from the south end of Headon Hill to Totlands and Colwell Bays, and to the absence of stratigraphical evidence at Brockenhurst—the superposition is not clear, the order of succession laid down originally by the Geological Survey is adhered to by most geologists[2].

The strata of the upper and thicker division of the Headon series are of the same character precisely as those of the lower division; and with the exception of a few additional forms (Bulimus, etc.) the same species of organic remains are also common to the two.

The Osborne Series consists of passage-beds containing some twenty to thirty species, none of them peculiar to this group, although presenting some well-marked varieties.

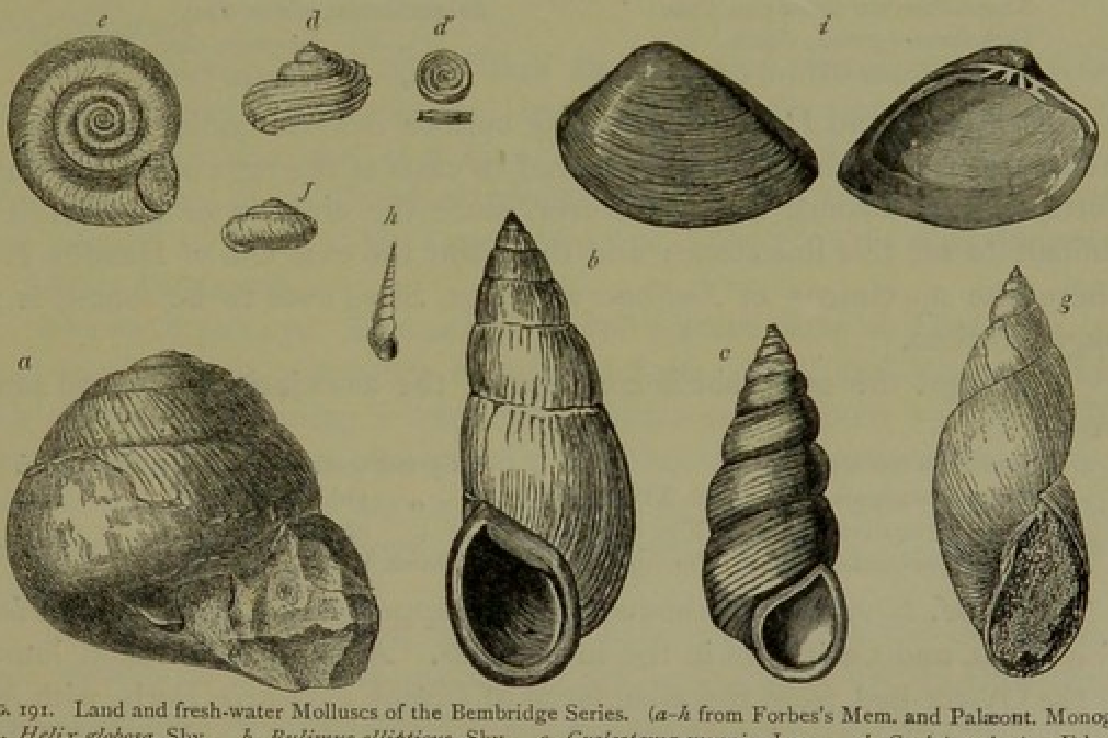

FIG. 191. Land and fresh-water Molluscs of the Bembridge Series. (*a–h* from Forbes's Mem. and Palæont. Monog.) *a. Helix globosa*, Sby. *b. Bulimus ellipticus*, Sby. *c. Cyclostoma mumia*, Lam. *d. Cyclotus cinctus*, Edw. *d'. Operculum of Cyclotus.* *e. Planorbis rotundatus*, Brard. *f. Helix Vectensis*, Edw. *g. Limnæa longiscata*, Brard. *h. Melania turritissima*, Forb. *i. Cyrena semistriata*, Desh.

The Bembridge Series. Overlying the last is a series of sands, white and green marls, light-coloured limestones, and shales. Marls predominate in the upper part and limestones in the lower. Unlike the Headon

[1] 'Quart. Journ. Geol. Soc.,' vol. xxxvi. p. 137; and vol. xxxviii. p. 461.

[2] Keeping and Tawney, 'Quart. Journ. Geol. Soc.,' vol. xxxvii. p. 85, 1881.

limestones, the limestones of this series are persistent from one end of the island to the other, and are characterised by many well-marked fossils, including some important Mammalian remains. These limestones, more compact than those of the Headon series, are well seen in the cliff-section of Whitecliff Bay, and they form also the reef known as the Bembridge Ledge. They abound in species of Limnæa, Planorbis, and Paludina, generally in the state of casts.

The main bed of limestone, twenty-four feet thick, used to be largely quarried as a building-stone at Binsted, near Ryde, and it is there that the chief Mammalian remains have been found. It thence ranges by Cowes to Sconce Point; and occurs again in the upper part of Headon Hill, where it is about fifteen feet thick. It is everywhere very fossiliferous, the following being the more common fossils :—

Cyclostoma mumia, *Lam.* Fig. 191, *c.*	Achatina costellata, *Sby.*
Limnæa longiscata, *Brongn.* Fig. 191, *g.*	Bulimus ellipticus, *Sby.* Fig. 191, *b.*
Planorbis rotundatus, *Brand.* Fig. 191. *e.*	Helix globosa, *Sby.* Fig. 191, *a.*
,, obtusus, *Sby.*	,, Vectensis, *Edw.*
Paludina globuloides, *Forb.*	Chara tuberculata, *Lyell.*

Teeth and bones are also met with of—

Anoplotherium commune, *Cuv.*	Palæotherium minus, *Cuv.*
Dichobune cervina, *Owen.*	,, magnum, *Cuv.* Fig. 193.
Chæropotamus Cuvieri, *Owen.*	,, crassum, *Cuv.*

At Sconce and Headon Hill some curious oviform bodies are found in the limestone, which have been referred to casts of the eggs of a fresh-water Tortoise. At Sconce Point, however, since the erection of the fort, it is difficult to see this limestone; and the pit at the east end of Headon Hill, where the specimens of *Bulimus ellipticus*, Sby., used to be found, is no longer worked.

Amongst the other shells common in the associated marls and sands are—

Cerithium mutabile, *Lam.*	Cyrena semistriata, *Desh.* Fig. 191, *i.*
Melania muricata, *Wood.* Pl. XIV, fig. 7.	,, pulchra, *Sby.*
,, turritissima, *Forb.* Fig. 191, *h.*	,, obovata, *Sby.*
Melanopsis carinata, *Sby.* Fig. 191, *i.*	Ostrea Vectensis, *Forb.*

The *M. turritissima* abounds in the upper, and *Cyrena semistriata*, *C. obovata*, and Cerithium in the lower beds. Another subdivision, known as the Oyster-bed, from the abundance of *Ostrea Vectensis*, Forb., with *Nucula similis*, Sby., etc., is to be seen below St. Helen's and at Whitecliff Bay.

The Hempstead Series is limited to a small outlier, of which a good section is exposed in the cliff near Hempstead Farm, two miles east of Yarmouth, in the Isle of Wight. Resting on the Bembridge series, and extending to the top of the cliff, which is 210 feet high, it consists of a succession of beds of marls and clays, some of them green and mottled, but others more like the grey and brown clays with septaria and selenite of London and Barton. At the base is a well-marked bed, called by

Forbes the 'Black Band,' with numerous shells, carbonaceous matter, imperfect leaf-impressions, and seed-vessels. Forty feet higher is another well-marked zone called the 'White Band,' a ferruginous stratum full mainly of bleached single valves of *Cyrena semistriata*, and some other shells peculiar to it. The upper beds with Ostrea, Cerithium, Natica, etc. are more distinctly marine.

The common and characteristic fossils of the Hempstead beds are,—

Cerithium plicatum, Lam. Pl. XIV, fig. 5.
,, elegans, *Desh.*
,, Lamarckii, *Brongn.*
Melania fasciata, *Sby.*
,, muricata, *Wood.* Pl. XIV, fig. 7.
Melanopsis carinata, *Sby.* Fig. 190, *c.*
Natica labellata, *Lam.*
Rissoa Chastelli, *Nyst.* Pl. XIV, fig. 6.
Voluta Rathieri, *Héb.* Pl. XIV, fig. 4.
Chara medicaginula, *Brongn.*
Corbula Vectensis, *Forb.*
,, subpisum, *D'Orb.* Pl. XIV, fig. 11.
Cyclas Bristowi, *Forb.*
Cyrena semistriata, *Desh.* Fig. 191, *i.*
Ostrea callifera, *Lam.* Pl. XIV, fig. 9.
Mya minor, *Forb.*
Unio Gibbsii, *Forb.*
Cytheridea Muelleri, *Münst.*
Candona Forbesii, *Jones.*
Hyopotamus bovinus, *Owen.*

Forbes gave the name of 'Corbula-bed' to the topmost bed (20 feet thick) of the series, from its abounding with two species of Corbula; while some beds a little lower are characterised by the abundance of *Cerithium plicatum.*

The plant-remains in the Black Band are of considerable interest, including, according to Professor Heer[1], seeds of Nymphæa and Chara, leaves of Nelumbium and of a Fan-Palm (*Sabal major*), with fragments of twigs and cones of an abundant conifer (*Sequoia Couttsiæ*, Heer). These were referred by Heer to the Lower Miocene,—the zone we now designate the Upper Oligocene.

Bovey Tracey. In a valley on the eastern slope of Dartmoor is a small local deposit, consisting of carbonaceous, china, and pottery clays, with lignites, and having a maximum thickness of about 130 feet. No organic remains, except plants and a few fragments of insects, have been found in it. The plants have a marked analogy with those of Hempstead; and Heer considered the Bovey deposit to be of the same Miocene (Upper Oligocene) age.

The researches of Professor Heer[2] have shown that this remarkable flora consists of forty-nine species of plants, of which twenty-eight were new. Amongst them he reckoned two species of Vitis (by the grape-stones only), Ficus (three forms), Quercus, Laurus, three species of Cinnamomum, Proteaceæ of the genus Dryandroides, several Nyssæ, some of the seeds of which are very like those of an American species, Andromeda, and seeds of Gardenia and of Nymphæa, a Eucalyptus, a Eugenia, and fruits of uncertain

[1] 'Quart. Journ. Geol. Soc.,' vol. xviii. p. 369.
[2] 'The Lignites of Bovey Tracey,' by W. Pengelly and Prof. Heer, 'Phil. Trans.' for 1862.

affinities; together with one species of Palmacites[1]. The most abundant plants are a species of Fern[2] (*Pecopteris lignitum*, Gieb.), two species of Cinnamomum (*C. lanceolatum*, Ung., and *C. Scheucheri*), and the peculiar

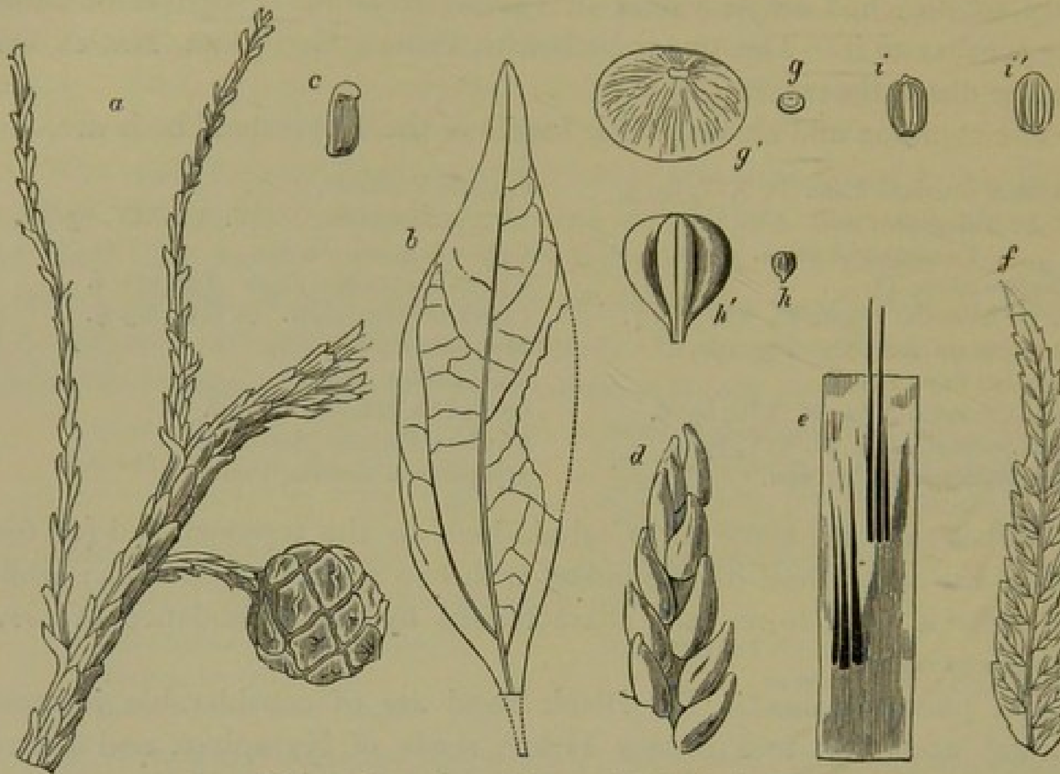

FIG. 192. Bovey Tracey Plants and Seeds. (*After Heer.*)
a. Sequoia Couttsiæ, Heer. *b. Cinnamomum lanceolatum*, Ung. *c. Carpolithes Websteri.* Br. *d. Gardenia Wetzleri*, Heer. *e. Palmacites Dæmonorops*, Ung. *f. Pecopteris* (Osmunda) *lignitum*, Gieb. *g, g'. Nymphæa Doris*, Heer. *h, h'. Vitis Hookeri*, Heer. *i, i'. Nyssa Europæa*, Ung.

Conifer, *Sequoia Couttsiæ*, Heer[3]. The cones and peltate scales of the last-named tree, with its branches and wood, form, with the Pecopteris, the matted peaty masses or beds of lignite.

The clays and grits of Bovey Tracey have been derived from the adjacent decomposing old granite tract of Dartmoor. The clay is almost a pure kaolin.

The Mull and Antrim Flora. In Scotland and Ireland, isolated leaf-beds are found in Mull and County Antrim. At both places they are associated with great masses of basalt, between successive layers of which, thin argillaceous and other beds with leaf-impressions occur. Nine species were described by Ed. Forbes[4] from Mull, where they were discovered by the Duke of Argyll; and about thirty species have been described by W. H. Baily[5] from the north of Ireland. The Gymnosperms of Mull have

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[1] The question has been raised whether this supposed prickly Palm may be a Cactus.

[2] *Osmunda*, according to Gardner and von Ettingshausen, 'Pal. Soc. Monogr.' 1881, p. 49, &c.

[3] Possibly *Athrotaxis*, according to J. S. Gardner, 'Pal. Soc. Monogr.' 1884, pp. 90–91.

[4] 'Quart. Journ. Geol. Soc.,' vol. vii. p. 103.

[5] 'Rep. Brit. Assoc.' from 1879 to 1884.

been figured and described by Mr. J. S. Gardner in the 'Palæontographical Monographs for 1883–4.' Amongst these are many new species. The following are a few of the forms in the Scottish beds :—

Sequoia (Athrotaxis ?) Couttsiæ, *Heer.*	Pinus plutonis, *Baily.*
„ Du-Noyeri, *Baily.*	Viburnum Whymperi, Heer.

These beds were considered by Heer to be of Miocene age, but Mr. J. S. Gardner questions this conclusion, and is of opinion that these plants, as well as those of Bovey Tracey, are of Eocene age. The evidence is, however, by no means conclusive. With the exception of the *Sequoia* (or *Athrotaxis*) *Couttsiæ*, all the Gymnosperms described by Mr. J. S. Gardner from Ireland are new species; and plants without the corroborative evidence of other fossils and superposition are not sufficient to settle questions involving approximate date. Saporta observes also of the flora of the Oligocene period, that it is at first very similar to that of the Eocene, and remarks that in the Miocene period the palms are mostly those of the preceding Oligocene period; while species of Sequoia, especially the *S. Couttsiæ*, although occurring in the Oligocene, predominate more in the Miocene period. Heer did not fail to notice the presence of some Eocene species at Bovey Tracey, but he considered that the many continental Tongrian and Aquitanian species outweighed the few Eocene relations of that flora.

Foreign Equivalents. The Oligocene series is of great importance on the Continent, being largely developed in North-Western and Central Europe, as well as in Switzerland and adjacent districts.

Belgium[1]. The continuity of common general characters, so conspicuous in the Eocene strata of the Anglo-Belgian Basin, ceases in the Oligocene. In Belgium it consists partly of marine and partly of fluvio-marine strata, which have been grouped by Dumont and later Belgian geologists as under :—

Oligocene	Upper		The Sands of Bolderberg (?).
	Middle	Rupellian System.	The Clays of Boom and Sands of Klein-Spauwen and Bergh; the Clays of Henis.
	Lower	Tongrian System.	The Sands of Neerrepen and Grimmertingen. The Glauconiferous Sands of Tongres.

The Tongrian rests on an eroded surface of the Eocene strata, and extends over the Cretaceous strata beyond. At the base is an irregular bed of small flint pebbles and gravel. Amongst the characteristic Mollusca are *Ostrea ventilabrum*, Goldf., *Cytherea incrassata*, Sby., *Leda Deshayesiana*, Duch., *Cerithium trochleare*, Lam., *Voluta decora*, Beyr., *Pleurotoma bellula*, Phill., etc. In the succeeding fluvio-marine beds of the Lower Rupellian are found *Limnæa acutibalis*, Sandb., *Hydrobia Chastelli*, Nyst, *Corbula subpisum*, D'Orb., *Cerithium plicatum*, Lam., *C. elegans*, Desh., *Cyrena*

[1] Dewalque, 'Description Géologique de la Belgique;' Mourlon, 'Géologie de la Belgique.'

semistriata, Desh., etc.; while in the Upper Rupellian is another marine fauna with *Nucula Duchasteli*, Nyst, *Cardita Kicksii*, Nyst, *Natica Nysti*, D'Orb., *Voluta Ratheiri*, Héb., *Rostellaria ampla*, Brand., etc. The 'Argile de Boom,' which around Antwerp attains a thickness of 200 feet, resembles very closely, in its general composition and the facies of its fauna, the London Clay to which it was originally referred.

The fine white quartzose sands of Bolderberg, without fossils, are referred by the Belgian geologists to the Oligocene; but it may be doubtful whether the upper beds, with the silicified fossils (usually in a fragmentary state), and amongst which are *Isocardia harpa*, Goldf., *Oliva flammulata*, Lam., *Ancillaria obsoleta*, Brocc., *Turritella attrita*, Nyst, *Arca latesulcata*, Nyst, *Corbula striata*, Nyst, etc., should not be referred to the Miocene.

France. Overlying the Sands of Beauchamp and the fresh-water 'Calcaire de Saint-Ouen' of the Paris Basin[1], is a series of fluvio-marine and marine strata of great interest. By some geologists the lower portion of these beds is included in the Eocene, and the upper in the Miocene, whereas by others they are grouped in the Oligocene, although there is still some little uncertainty as to where exactly to place the divisional lines.

Oligocene . .	Upper. (*Middle Miocene: Aquitainian, part*).	'Calcaire de Beauce' and 'Meulières de Montmorency;' Sand and sandstone of Ormoy and Fontainebleau.
	Middle. (*Lower Miocene: Tongrian*).	Sand of Etampes and Pierrefitte; Calcaire de Brie (or Travertin moyen), and Chateau Landon.
	Lower. (*Upper Eocene: Ligurian*).	Gypsiferous marls of Montmartre and marine green sands of Monceaux.

The lower marine sands are very variable, and contain many species common to the Sands of Beauchamp, such as *Cerithium tricarinatum*, Lam., *Lucina saxorum*, Lam., etc., but with other fossils peculiar to them; while the overlying marl is characterised by the presence of *Pholadomya Ludensis*, Desh., and other new forms. To these succeed the well-known series, 150 to 200 feet thick, of green and white marls interstratified with lenticular masses of gypsum,—often remarkable for the regularity of its prismatic jointing,—so largely quarried at Montmartre for the manufacture of Plaster of Paris[2]. Those quarries furnished Cuvier with a large number of the fossils described in his great work on the extinct Tertiary Mammals[3] —the *Palæotherium*, *Anoplotherium*, *Lophiodon*, *Xiphodon*, etc. The few molluscs which accompany these remains are of fresh-water genera. The

[1] For the broad divisions of the Paris Basin, see Chas. D'Orbigny's 'Tableau Synoptique du Bassin Parisien'; the various papers by Hébert in the 'Bull. Soc. Géol. de France'; and one by G. Dollfus in 3rd Ser., vol. vi. p. 269.

[2] Another mineral associated with these beds is Menilite,—a hydrated siliceous concretion of an opaque brown colour, and with a resinous or waxy lustre. Geodes of sulphate of strontian also occur.

[3] 'Ossements fossiles,' Paris, 1824. See also Cuvier et Alex. Brongniart, 'Description Géologique des Environs de Paris,' 1822.

more common species are *Limnæa strigosa*, Brongn., *Cyclostoma mumia*, Lam., *Planorbis planulatus*, Desh. The remains of Trionyx, Crocodile, and Fishes are also common.

To these succeed green marls and a local travertine, known as the 'Calcaire de la Brie' or 'Travertin moyen.' It contains in places large concretionary blocks of more or less hydrous, opaque, whitish silex, very cellular, with a few rare fresh-water shells and Chara seeds. These 'Meulières' are largely worked in the neighbourhood of La Ferté-sous-Jouarre, for millstones and basement walls.

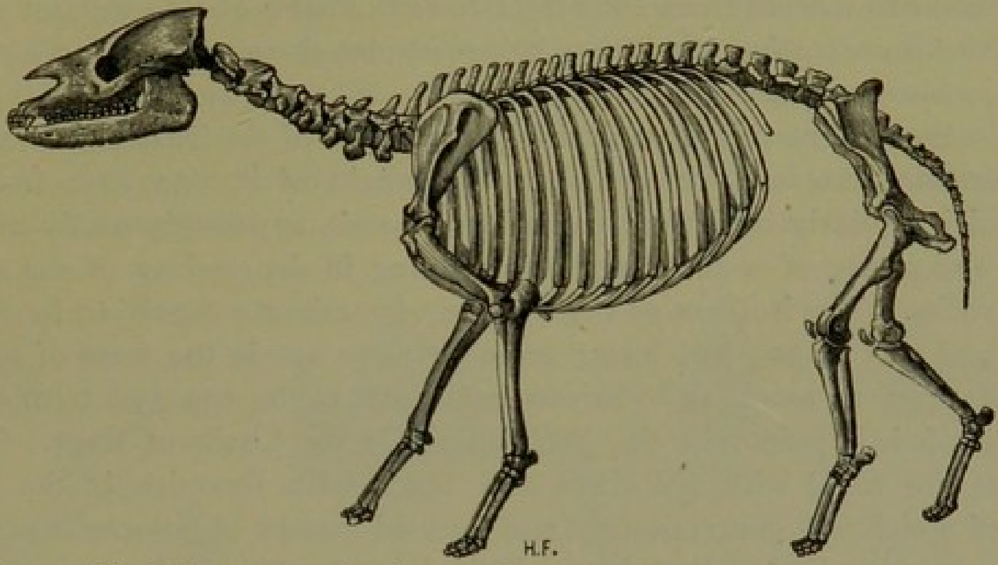

FIG. 193. *Palæotherium magnum*, Cuv. (as restored by Gaudry after a nearly entire specimen found in the gypsiferous beds of Vitry-sur Seine), $\frac{1}{25}$.

In the more southern part of the Paris Basin, these freshwater beds are succeeded by the marine sands of Etampes and the well-known Fontainebleau Sandstone. The latter sometimes pass almost into a quartzite, forming a much-used paving-stone; in other places the sands have a calcareous cement, which in solidifying has agglutinated the quartzose sand into the form of the rhomboidal crystals of calc-spar. At Etampes the sands are very fine and white, and abound with shells in a beautiful state of preservation. Amongst the most common are—

Pectunculus obovatus, *Lam.*	Natica crassatina, *Desh.*
Cytherea incrassata, *Sby.* Pl. XIV, fig. 8.	Cerithium plicatum, *Brug.* Pl. XIV, fig. 5.
Ostrea cyathula, *Lam.*	,, trochleare, *Lam.*
Corbula subpisum, *D'Orb.* Pl. XIV, fig. 11.	Voluta Rathieri, *Héb.* Pl. XIV, fig. 4.

These beds are overlain by another fresh-water lacustrine deposit, the 'Calcaire de Beauce' or 'Travertin Supérieur,' with subordinate marine beds containing *Cerithium Lamarckii*, Brongn., *C. plicatum*, Brug., etc. These upper zones are characterised also by various species of Anthracotherium and Hyopotamus.

The Oligocene beds of Brittany[1] are separate and distinct from those

[1] Vasseur, 'Terrains Tertiaires de la France Occidentale.'

of the Paris Basin, but contain a few of the same fossils, such as *Cerithium plicatum*, *C. Lamarckii*, *Cytherea incrassata*, *Natica crassatina*, etc., together with a large number of Foraminifera. The Tertiary strata of this district consist of a calcareous freestone, about 100 feet thick (largely worked in the neighbourhood of Rennes), with an overlying bed of 'Meulière'; they rest directly on Palæozoic and Crystalline rocks.

The Montmartre series is represented in the Bordeaux district by beds with *Limnæa longiscata*, Brongn., *Planorbis rotundatus*, Brong., and a 'molasse' with *Palæotherium minus*, Cuv., and *Xiphodon gracile*, Cuv., to which succeed marine calcareous freestones (*Calcaire à Astéries*) and marls, with *Natica crassatina*, *Cerithium plicatum*, etc., showing relations with the Fontainebleau series of the Paris Basin.

To the east of this area, in the Department of the Tarn and Garonne, the Jurassic plateaux, which rise to the height of 800 to 1000 feet, are covered irregularly by a very anomalous deposit, apparently partly of subaërial and partly of sedimentary origin, lying in depressions of the calcareous rocks. The hollows or cavities are of moderate depth, 10 to 20 feet wide, and 100 to 300 feet long; some however are in the form of funnel-shaped pipes, as much as 80 to 100 feet across at the top, and terminating downwards in a point like the gravel-pipes in the Chalk of Kent. These cavities are filled with red clays and marls with limonite, in the lower part of which are concretionary and banded masses of phosphate of lime, white, grey, and blue in colour. This Phosphorite of Quercy[1], as it is termed, contains also chlorine, fluorine, and iodine, with traces of bromine. Imbedded in the associated clay is a vast number of Mammalian remains, in some cases in innumerable fragments, in others with the jaws, skulls, and portions of the skeletons entire. Fifty-eight genera have been discovered, of which twenty-five are those of the Gypseous series of Paris; the remains of Batrachians, Ophidians, and occasionally of Bats are also met with in considerable quantity. All the bones are changed into phosphate of lime. Large quantities of land and fresh-water shells (*Cyclostoma*, *Limnæa*, *Planorbis*) are likewise found in places. The exact conditions under which these deposits have been formed present an interesting and difficult problem. The animals generally seem to have been entombed suddenly, and fossilised rapidly; and it is probable that the phosphoric acid had an organic origin.

The 'Poudingue de Palassou' of the Pyrenees—a remarkable conglomerate, attaining a thickness of 3000 to 3500 feet—is supposed to be of the same age. It is formed of pebbles, usually small, but some three feet in diameter, derived from Cretaceous limestones with flints, with others of Silurian and Crystalline rocks. Scant remains of Palæotherium, and a few other fossils, have been found associated with these strata.

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[1] Peron, 'Bull. Géol. Soc. France,' 3e sér., vol. ii. p. 108; Filhol, 'Ann. des Sc. Géol.' 1872.

In the neighbourhood of Carcassonne the rocks of this age consist of soft sandstones with subordinate beds of gypsum and conglomerate, containing many of the same Palæotherian Mammals as in the Paris and Bordeaux Basins. In the Montpellier district there are lignitiferous beds with *Palæotherium* and *Xiphodon*. Other Upper-Oligocene strata, with *Cerithium plicatum*, extend into Languedoc and Provence.

To this period also belongs the interesting small but thick lacustrine deposit of Aix-en-Provence, composed of a series of red marls and sandstones, and a basal conglomerate, succeeded above by white limestones and grey marls, with beds of gypsum and lignite. Amongst the Mammalian remains are those of *Palæotherium magnum*, Cuv., *P. medium*, Cuv., *Xiphodon gracilis*, Cuv., *Anoplotherium commune*, Cuv., etc.; and amongst the plants are species of Cinnamomum, Laurus, Quercus, Cercis, Callistris, Juniperus, Flabellaria, etc. M. de Saporta[1] remarks on the richness, novelty, and singular mixture of forms in this flora. One of

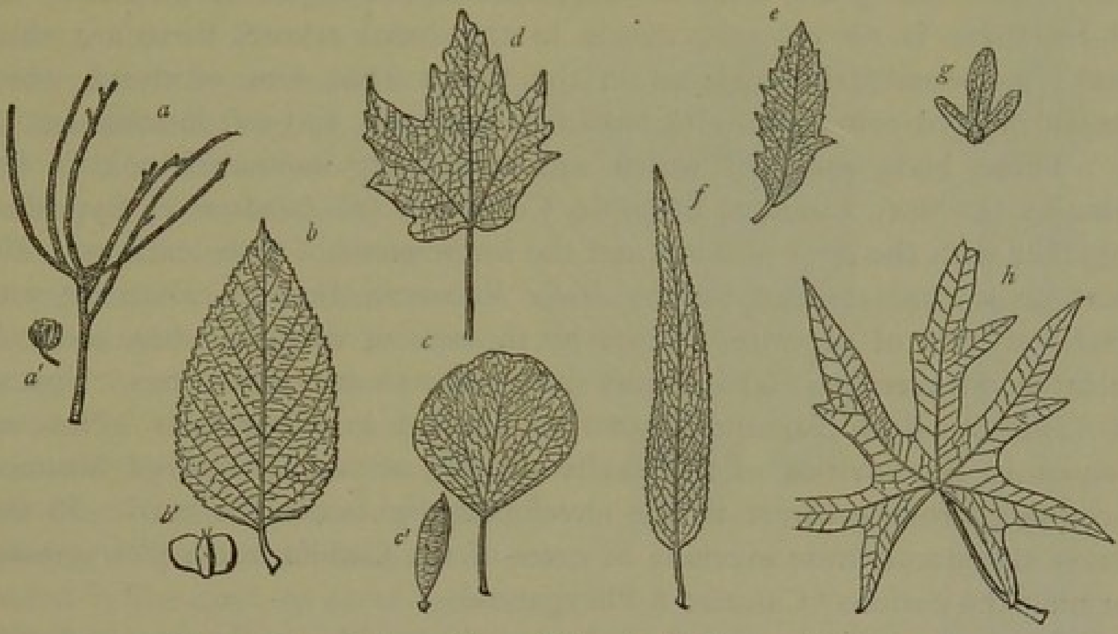

FIG. 194. Lower Oligocene (Gypse d'Aix and other) Plants. (After Saporta.)
a, a'. Widdringtonia brachyphylla, Sap. *b, b'. Betula Dryadum*, Brong. (Armissan). *c. Cercis antiqua*, Sap. *d. Acer primævum*, Sap. (Saint-Zacharie). *e. Myrica Matheronii*, Sap. *f. Salix aquensis*, Sap. *g. Palæocarya atavia*, Sap. *h. Aralia multifida*, Sap.

the Palms (a Flabellaria) has its nearest affinities with a Chinese species; another, a Musa, with the existing Banana of Abyssinia; a Proteacea (?) has its representative in Australia; and a Cercis resembles the existing Judas Tree. Altogether, however, the flora of this time, and of the whole of the Oligocene period, is, he considers, more specially allied to that of the interior of Africa. It is that of a climate hot and dry, with seasons of heavy rain, and where the summer heat, like the winter cold, checks vegetation, and the plants revive in early winter.

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1 'Le Monde des Plantes,' p. 244.

The remains of Insects, including Dragon-flies, Butterflies, winged Ants, Bees, etc., abound; and in some cases there is even the traces of colour. A small fresh-water fish, the *Lebias cephalotes,* occurs in thousands; its impressions are often in a wonderfully perfect state. The genus still survives in the fresh waters of Sardinia and Northern Africa.

Whilst these fluvio-marine strata were forming in Northern and South-western France, the Central area was occupied by an extensive fresh-water lake, in which were accumulated a remarkable series of beds of lacustrine and volcanic origin. The surrounding granitic and gneissic rocks there furnished at first, as they did during the Carboniferous period, the materials of the strata,—the basement Tertiary beds, which are 500 to 600 feet thick, consisting of felspathic sandstones, grits, and conglomerates, with mottled and sandy clays, resulting from the decomposition of the plutonic rocks. These strata are of Middle or Lower Oligocene (Tongrian) age, and it would seem that it was not until afterwards, or during the later Oligocene times, that the great volcanic eruptions of Auvergne commenced; for, whilst there is no volcanic debris in the basal arkose, there are thick banks of peperite intercalated in the upper 1000 feet of strata, which consist of light-coloured marls, lenticular gypsums, and soft limestones.

These beds, some of which are very finely laminated, contain fish remains (Lebias), Limnæa, Bythinia, Cerithium (*C. Lamarckii*), Cyprideæ, together with the eggs of Birds and the impressions of their feathers. The next beds, characterised by the *Helix Ramondi,* Brongn., alternate with stratified beds of peperite, formed by showers of volcanic ashes, and with calcareous travertines and siliceous sinters due to mineral springs. Species of Limnæa, Bythinia, and Planorbis abound in other beds. Not unfrequently the cavities of the shells are full of animal-derived bitumen, forming a strong contrast to the enveloping light-coloured marl. In this series also occur those myriads of cases of the Caddis-worm (*Phryganea*), forming the curious 'Calcaire à Phryganes.'

Later on lava-streams flowed over these older sediments, and were succeeded by beds with Melania, Unio, Cyrena, and a flora of Laurus, Liquidambar, Cinnamomum, Myrica, and other plants, having Australian affinities. It would seem from the vast showers of ashes that the early eruptions were paroxysmal; but that, as the lakes became shallower and drier, the basalt welled out with less, if any, explosive action. At the same time a varied Mammalian fauna set in, consisting of species of *Palæotherium, Anthracotherium, Dremotherium, Cainotherium,* etc.[1], together with the remains of Crocodiles, Tortoises, and of Birds. Eggs also are found entire, as if deprived of the care of the parent birds, by the latter having been suddenly overwhelmed or accidentally killed (possibly by volcanic vapours).

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[1] See the various works of M. Pomel and M. P. Gervais.

There were other smaller fresh-water lakes in the South of France, such as those of Armissan near Narbonne, of Saint-Zacharie, and of Gargas, on the shores of which flourished a rich and typical Upper-Oligocene vegetation, consisting of numerous species of large coniferous trees, such as Sequoia (*S. Sternbergii*, Göpp.), Glyptostrobus, Taxodium, Libocedrus (*L. salicornoides*, Endl.), and Chamæcyparis, together with species of Callistris, Widdringtonia, Comptonia, Oaks with coriaceous leaves, Celastrus, Diospyros, Aralia, Palæocarya, Mimosa, Alnus, Betula, Acer, Populus, Palms (*Sabal major*, Ung., *Flabellaria latiloba*), and various water-plants.

Amongst the latter there is one requiring special notice—the *Rhizocaulon polystachium*, Sap. This fine plant belonged to an extinct genus which first appeared in the later Cretaceous times, but had its greatest development in the latest Oligocene times. Saporta says it has left its traces everywhere in the South of France, and only there. Like the reeds and sedges of the present day, it lived in still and shallow waters, with innumerable roots going down into the soft mud. Along the shores of the ancient lakes, these plants formed vast dense colonies, rising several metres above the surface of the waters, and, like the existing Pandanus, throwing out from their stems numerous radicles, which descended and rooted in the mud, so as to form additional supports to the plants with their elegant heads of ribboned leaves and flowers[1].

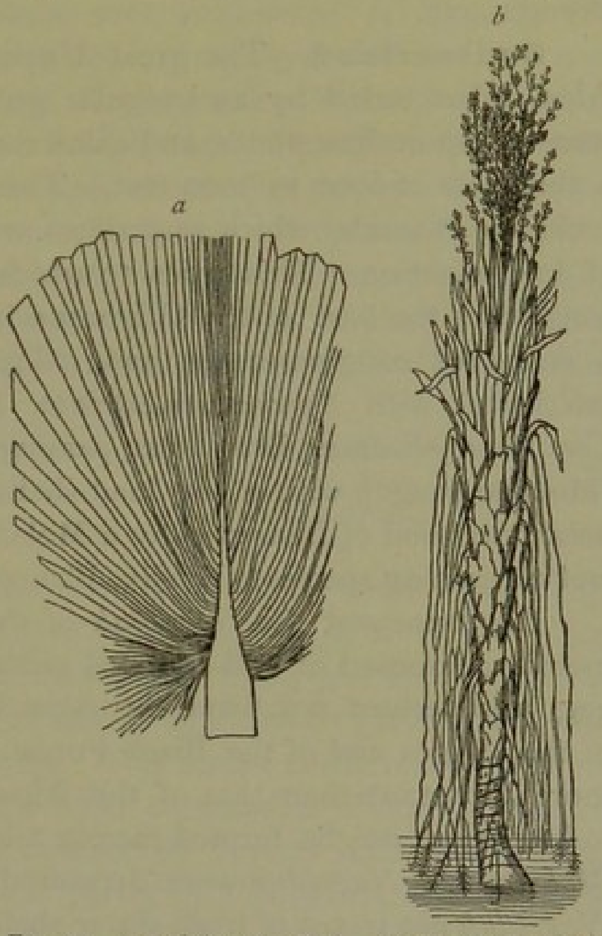

FIG. 195. *a. Sabal major*, Ung. *b. Rhizocaulon polystachium*, Sap. (Saint-Zacharie). (After Saporta.)

The water-plants of this period seem to have had a luxuriance of growth only seen now, but on a smaller scale, in Egypt, Nubia, and the inundated Savannahs of Guiana.

Another aspect of the Oligocene is presented by the ferruginous deposits of Eastern France and the Jura. Covering, or more commonly merely filling pipes and fissures in, the Jurassic rocks, is a red clay, with limonite in pisiform grains and concretions, termed *Bohnerz* by the Swiss,

[1] Saporta, *Op. cit.*, p. 266.

and *Depôts sidérolithiques* by the French geologists. This deposit contains remains of *Palæotherium magnum*, *Anoplotherium commune*, etc., with pebbles of the subjacent rocks. It seems probable that this was a subaerial deposit, accompanied by ferruginous springs, if not, as some would suggest, by mud-volcanoes; the occasional cementation of the materials by silica, and the presence of chalcedonic quartz, indicate, also, the action of siliceous springs. The tract of country covered by this peculiar ferruginous deposit is very considerable.

To this succeeds in places a thick mass of mottled clays with beds of gypsum and lignite, and then a lacustrine limestone and marls, with *Limnæa longiscata*, Brong., *Planorbis planulatus*, Desh., *Chara helicteres*, Brongn., etc.

Switzerland. The great Upper-Eocene Nummulitic series of the Alps is succeeded by an irregular group of schistose rocks, flaggy sandstones, impure limestones, and calcareous sandstones, which attain in places a thickness of 6000 to 7000 feet. The only organic remains found in these rocks are 'fucoids,' which sometimes are very abundant, but always difficult of determination. This series, to which the name of *Flysch* has been given, constitutes the base of the Oligocene in the Alpine area. Above it comes a series of conglomerates and calcareous sandstones (Molasse marine inférieure) with *Cyrena semistriata*, Desh., *Pectunculus obovatus*, Lam., *Cerithium plicatum*, Brug., etc., passing up into red sandstones and marls (Molasse rouge), with a few land-shells and plants, and succeeded in the neighbourhood of Lausanne by a Molasse with beds of lignite and gypsum, and containing species of Helix, Planorbis, Limnæa, etc.

On these rest the *Nagelfluh* of the Righi, a thick (1000 feet) conglomerate composed of well-rounded pebbles, mostly about the size of a hen's egg, and derived not from the Alps, but from the more distant mountains of the Vosges and of the Black Forest. Those ranges, however, were then more important than that of the Alps, which, not having been yet raised to its present height, formed merely a line of high islands, around which the *Molasse* and *Nagelfluh* were deposited. The only organic remains in the *Nagelfluh* are traces of fresh-water shells and of plants.

Germany. It is in this part of Europe that the Oligocene series has its greatest development, spreading over a large portion of North Germany, and occupying the well-known basins of Mayence and Vienna. Geologically, these formations of Northern Germany are important from their rich and varied fauna, and economically from their thick masses of workable lignites.

The lower or lignitic series consists of white quartzose sands with subordinate pebble-beds, chiefly of white quartz, which, when consolidated by a siliceous cement, form hard conglomerates. These sands alternate with light-coloured and white plastic clays and grey shales with vegetable impressions and beds of lignite, forming altogether a deposit not unlike that represented in modern times by the delta on which Venice stands. (Vol. I, p. 85.) The Oligocene lignites attain, however, a much greater thickness, the beds at Meissner (Vol. I, p. 390) being above 100 feet thick; while at Magdeburg, Zittau, and other places there are beds from 50 to 150 feet thick; but more generally the thickness varies from three to ten feet. At Riestadt in Saxony, in a thickness of 300 feet, there are six beds of lignite (Credner, p. 594). The lignite is usually black, earthy, or lustrous; but some of the beds are yellow, light and spongy, and fusible like wax: these are used for the manufacture of paraffine.

The lignite is formed generally of coniferous woods such as trunks of Taxites, Taxoxylon, Cupressinoxylum, and sometimes of Sequoia (*S. Couttsiæ*) and Palmacites; while in the accompanying shales are leaves of Laurus, Ficus, Quercus, Cinnamomum, Dryandroides, Acer, Juglans, etc., together with those of Palms (*Sabal*, *Flabellaria*). This flora has a sub-tropical character, chiefly of Indian and Australian types. Associated with the lignites are beds with numerous fresh-water shells and fishes.

These deltaic and fresh-water deposits were then submerged, bringing back the sea over the large area now occupied by the beds of Egeln and the sands and clays of Magdeburg. These beds contain an abundant Molluscan fauna, including—

Ostrea ventilabrum, *Goldf.*
Arca appendiculata, *Sby.*
Cardita Dunkeri.
Cytherea Solandri, *Sby.*
Buccinum bullatum.
Voluta decora, *Beyr.*
Pleurotoma Beyrichi, *Phil.*
Cerithium læve.

It is on this horizon that occur the celebrated Amber beds of Samland, on the shores of the Baltic. The amber occurs in lumps, of various sizes, in a bed of greenish sand, from four to six feet thick, just below the sea-level, and is overlain by some 60 to 70 feet of lignitiferous green sands with species of Taxodium, Cinnamomum, etc. This amber is the resin of several species of Pine, amongst which the most common is *Pinus succinifer*. It abounds in the remains of well-preserved Insects and Myriapods; and is obtained partly by digging and partly by the action of the sea in washing it out of the beds.

The Middle Oligocene consists of sands, sandstones, and clays, of which the sands of Stettin, and the sands and septarian-clays of Magdeburg, are examples. These beds are extremely rich in Foraminifera and Mollusca, amongst the latter of which are—

Leda Deshayesiana.
Pecten permistus.
Axinus obtusus.
Fusus Koninckii.
Borsonia gracilis.
Tornatella globosa.

In the Mayence basin [1] the Weinheim sands, which there form the base-

[1] For information respecting this Basin, see Hamilton in 'Quart. Journ. Geol. Soc.,' vol. x. p. 254; various papers by Sanderberger, Von Koenen, and Beyrich; and Von Hauer's 'Geologie.'

ment beds of the Oligocene, rest on Devonian rocks. Amongst numerous other fossils they contain—

Ostrea cyathula, *Lam.*
Pectunculus obovatus, *Lam.*
Cytherea incrassata, *Sby.* Pl. XIV, fig. 8.
Corbula subpisum, *D'Orb.* Pl. XIV, fig. 11.
Dentalium Kickxii, *Nyst.*
Natica crassatina, *Desh.*
Cerithium plicatum, *Brug.*
Voluta Rathieri, *Heb.* Pl. XIV, fig. 4.

While the overlying clay contains—

Cerithium plicatum, *Brug.* Pl. XIV, fig. 5.
" margaritaceum, *Nyst.*
Cyrena semistriata, *Desh.* Fig. 191, *i.*
Leda Deshayesiana, *D'Orb.*

In the Vienna Basin, the Middle Oligocene is represented by micaceous clays (Tegel) and sands with a group of fossils similar to those in the last-named group.

The Upper Oligocene has a more restricted range. It consists of a lignitic series with some very finely laminated carbonaceous shales (*Papierkohle*), and a flora analogous to that of the warm parts of North America, consisting of allied species of Porsites, Cupressinoxylon, Cinnamomum, Quercus, Nyssa, Juglans, etc. It contains also numerous Insects, Fishes (*Leuciscus*), and Batrachians. Near Osnabrück and Hildesheim higher marine beds, with *Pecten janus*, *Terebratula grandis*, and Echinoderms, occur. The Upper Oligocene is also often rich in Foraminifera which have been described by Reuss. The rich fauna of Cassel (Hesse-Darmstadt) belongs to this period.

The Older Extra-European Tertiaries. If a difficulty exists in drawing the lines of demarcation of the Oligocene series in Europe, it may be readily supposed that distance adds to that difficulty. Further eastward we can only treat of the Eocene and Oligocene as the 'Older Tertiaries' on the whole, and of the Miocene and Pliocene together as the 'Newer Tertiaries,' noting the subdivisions in a few cases where practicable.

Eocene (and Oligocene) strata extend through Asia Minor[1], form the Nummulitic rocks of Egypt, and are continued almost uninterruptedly through Persia[2] to North-Western India.

India[3]. There are considerable tracts of Older Tertiary strata in both Extra-Peninsular and Peninsular India. In the former area they form the Nari, Khirthar, and Ranikot beds of Sind, together with the Nummulitic beds of the Salt-Range (Punjab), of Assam, and Burmah; and in the Peninsular area they are found in Cutch and on the West Coast.

The soft sandstones, shales, and clays—often richly coloured—of the Ranikot group, with their subordinate beds of gypsum and lignite, are

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[1] De Tchihatcheff, 'Bull. Soc. Géol. de France,' 2e sér., vol. vii. p. 388.
[2] W. K. Loftus, 'Quart. Journ. Geol. Soc.,' vol. xi. p. 247.
[3] Medlicott and Blanford, *Op. cit.*, pp. 451–461.

about 2000 feet thick, and are considered to be of early Eocene age. But although the majority of the Foraminifera, Echinodermata, and Gasteropoda are of Tertiary forms (Nummulites, Operculina, Voluta, Terebellum, Rostellaria, etc.), there is an admixture of species with Cretaceous affinities in forms of Terebratula (*T. subrotunda*, Sby. ?), Salenia, Cyclolites, etc. The three species of Nautilus are also connected with Cretaceous rather than with Tertiary types.

The succeeding Khirthar group comprises the conspicuous Nummulitic Limestone, which varies in thickness from 1000 to 3000 feet. The most characteristic fossils are Nummulites and Alveolina: they are extraordinarily abundant, and include many European Eocene forms, such as *N. Ramondi*, Defr., *N. Biaritzensis*, D'Archiac, etc. With these are species of Cardita, Crassatella, Ovulina, Cerithium (*C. giganteum*, Lam.), of Tertiary forms, while the Cretaceous *Ostrea vesicularis*, Lam., still survives.

The thick sandstones of the Nari group are destitute of animal remains; but in the limestone at its base marine fossils occur, amongst which are large Foraminifera and a European Upper-Eocene or Oligocene species of Nummulite (*N. garansensis*, D'Arch.). With these occur Mollusca having Miocene affinities, with others of Eocene forms, such as *Natica patula*, Desh., *N. sigaretina*, Lam., *Ostrea flabellula*, Lam., etc.; hence Dr. Blanford is led to suppose that this group may perhaps occupy an intermediate position in the Tertiary series similar to that of the Oligocene of Europe.

The beds of rock-salt and gypsum at the base of the Tertiary series in the Kohát region (Punjab) are very important and remarkable. Hills 200 feet high are sometimes formed of pure rock-salt. As a rule, the salt contains sulphate of lime (gypsum), but none of the potassium and magnesium salts of the Salt-Range beds. These beds are unfossiliferous, but the overlying dark-red clay, grey sandstones, and limestones abound in places, as in the Salt-Range, with Nummulites, Alveolina, etc.

The Nummulitic rocks range, irregularly and with many changes, to Assam. In one place *Nummulites Lamarckii*, D'Arch., an Upper-Eocene species, is found. The important and extensive coal-seams of Assam are supposed to be of Middle Tertiary age. The coal is a true coal and not lignite. One seam (or group of seams) is 100 feet thick, and the coal-bearing series attains a thickness comparable with that of the true Coal-measures of Europe, viz. 8000 to 12,000 feet.

While there is this grand development of Lower-Tertiary Strata in Sind and the Punjab, the marine rocks of this age in the Peninsula are confined to a narrow belt on the Western Coast, being a prolongation of those of Sind. The Nummulitic limestones and conglomerates of Surat and Broach, which are from 500 to 1000 feet thick, are of this age. They contain *Nummulites Ramondi*, Defr. (of the Bayonne beds), *Natica longispira*, etc. In Cutch the Tertiary strata consist of gypseous shales, Nummulitic limestones, and a fossiliferous argillaceous group in which species of Turritella and *Venus granosa*, Sby., are common.

The high-level laterite has been referred to this period; but Dr. Blanford states that its age must remain undetermined until the mode of its formation has been more definitely ascertained. He points out, however, the great similarity of the Deccan laterite to some beds interstratified with the Nummulitic limestones and conglomerates of Guzerat and Cutch, as suggesting the probability that the two are contemporaneous.

The nearly continuous range of the Nummulitic beds from the South of Europe and Northern Africa to India, indicates what must have been a remarkable feature in the physiography of this area in Eocene times. It points to the existence of a large ocean-basin extending over this great continental area; and Dr. Blanford shows that at the same time an extensive continental land may then have extended from the Peninsula of India to the East Coast of Africa.

Australia. No Lower-Tertiary marine deposits have yet been found in the whole of Eastern Australia; but there are various argillaceous beds containing plant-remains, often covered by basaltic flows, and forming sometimes gold '*leads*,' which are generally referred to this period.

New Zealand[1]. No separating line can here be drawn between the Cretaceous and Tertiary strata. They are continuous, and pass one into the other, forming passage-beds that are wanting in Europe. The New-Zealand geologists designate those the Cretaceo-tertiary Formation. Its divisions are given in Table V (*ante*, p. 17). While some fossils, from the lowest to the highest parts of the Formation (which is from 2000 to 5000 feet thick), present a strong Tertiary facies, there are, even in the upper part, a few decidedly Secondary forms. The basement conglomerates are overlain by the New-Zealand coal-series. The coals are everywhere hydrous 'brown coals;' but on the West Coast there are some lower seams of valuable bituminous coal. Amongst the plants are species of Phyllites, Tæniopteris, Taxites, Dammarites, Araucarites, etc. Both the dicotyledonous and coniferous trees are of forms closely allied to those of the existing New-Zealand flora.

The upper marine beds contain species of Cardium, Hemicardium, Astarte, Rostellaria, Neæra, Pecten, Flabellum, etc., of Tertiary facies, with Ammonites, Belemnites, Ancyloceras, and other Cretaceous Cephalopoda, and bones of Saurians of the genera Plesiosaurus, Leiodon, etc. The occurrence of some beds of this age in the deep gold-drift deposits ('Leads') shows that there were great valleys excavated prior to the Kainozoic period.

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[1] See 'The Geological Formations of New Zealand,' by Dr. Hector, 'Proc. Roy. Soc. of N.S.W.,' 1879, and his 'Guide to the Geological Exhibits,' 1886.

The Upper-Eocene strata are remarkable for the evidences of intense volcanic activity which prevailed during that period,—for their interbedded contemporaneous volcanic rocks, their trachytic flows and volcanic breccias. In one part the strata pass into an Orbitolite limestone, and in the green sands at the base occur the remains of a huge Zeuglodont Cetacean (*Kekenodon*); amongst the other fossils are *Terebratella Suessi*, Pectens, and numerous Corals.

North America. Here, as in New Zealand, and to a certain extent in India, there is no break between the Mesozoic and Kainozoic series. The Lignitic group, which is Cretaceo-tertiary, we have already had occasion to notice (*ante*, p. 310). The Alabama group, which next succeeds in time, is the equivalent probably of the Upper Eocene and Oligocene of Europe. Strata of this age are extensively developed in Mississippi, Alabama, and Georgia, and in some parts of South Carolina and Virginia. They consist of lignites, marly and arenaceous limestones, dark-green sands, marls, etc., 3000 to 4000 feet thick. (Table II, p. 10.)

Amongst the fossils of this period are species of Pecten, Crassatella, Astarte, Cardium, Pseudoliva, Natica, Marginella, Cypræa, Voluta, etc. The common Bracklesham shell, *Cardita planicosta*, Lam., occurs in these beds. There are also three European Eocene Fishes—*Lamna elegans*, Ag., *Carcharodon angustidens*, Ag, and *Galeocerdo latidens*, Ag. The most notable of the marine forms, however, are, as in New Zealand, the Zeuglodonts, huge whale- or seal-like animals, one of which—*Zeuglodon cetoides*—must have been about 70 feet in length. With these are species of Sword-fish, Saw-fish, and of Snakes, Crocodiles, Turtles, and Tortoises.

But the most remarkable of the organic remains of the Far West are those of the wonderful animals described by Leidy, Marsh, and Cope, which include Quadrumana (*Notharctus*), Marsupials (*Triacodon*, *Stypholopus*), Rodents, Bats, Insectivores, Carnivores (*Oreocyon*, *Limnofelis*, *Mesomyx*), Horse (*Orohippus*), and the extraordinary horned Pachyderms of the new order, of Dinocerata, which includes the *Dinoceras* and *Tinoceras* of Marsh, the *Uintatherium* of Leidy, and *Eobasileus* of Cope. These gigantic animals were as large as an Elephant, without trunks, with two or more pairs of horns, and powerful canine tusks. The largest and most specialised of these creatures was the *Tinoceras* (Fig. 196), which abounded in the Middle Eocene but seems to have left no descendants. There are likewise in this Wyoming Basin genera allied to the Lophiodon and Palæotherium of the European Oligocene[1].

Here also is met with the supposed ancestral form of the Horse in

[1] The student should consult the magnificent works of Marsh, 'On the Dinocerata,' and of Cope, 'On the Vertebrata of the Tertiary Formations of the West.' In the inaccessible districts in which these deposits are situated, the work of collecting these remains proved one of great hardship and often of considerable danger.

the *Orohippus*, a small animal not larger than a Fox, with one large and three small toes, the latter destined to disappear gradually and become merely rudimentary in the successive stages through which the Horse passed—of *Anchitherium* (Miocene), *Hipparion* (Pliocene), to the existing form of Horse.

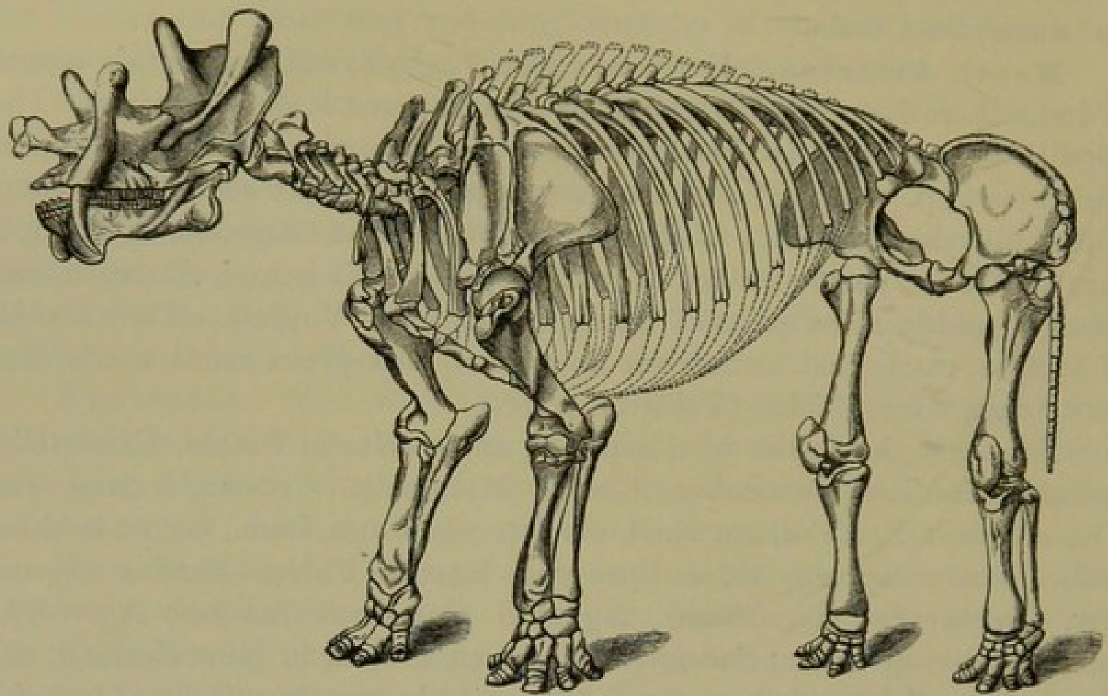

FIG. 196. *Tinoceras ingens; Wyoming, N. America.* $\frac{1}{30}$ nat. size (restored by Professor Marsh).

The remains of these remarkable groups of extinct Mammalia are found in vast fresh-water basins, lying in the Rocky-Mountain region. Some of the formations are from 6000 to 8000 feet thick, and situated several thousand feet above the sea-level. The strata, which are nearly horizontal, consist of sands and clays very slightly consolidated, and yielding easily to the action of winds and rain. Consequently they have weathered into the most singular forms, often resembling the towers, pinnacles, monuments, and walls of gigantic ruined cities. It is these curious deposits that constitute the 'Mauvaises Terres' of Colorado and California.

CHAPTER XXV.

THE MIOCENE SERIES.

NO MIOCENE STRATA IN ENGLAND. BELGIUM: DIESTIAN AND EDEGHEM BEDS. FRANCE: ABSENCE OF MIOCENE BEDS IN THE PARIS BASIN. SANDS OF THE ORLEANNAIS. FALUNS OF TOURAINE, ANJOU, AND BRITTANY. FALUNS OF BORDEAUX. LIMESTONES OF THE AGENAIS. BONE-BEDS OF SANSAN. MARLS OF AUVERGNE. BONE-BEDS OF MONT LÉBERON. SPAIN. PORTUGAL. THE MIOCENE (UPPER MOLASSE) STRATA OF SWITZERLAND. UPPER MIOCENE OF ŒNINGEN. HEER ON ITS FAUNA AND FLORA. TEMPERATURE OF THE PERIOD. SOUTH GERMANY. MAYENCE BASIN. VIENNA BASIN. NORTH GERMANY. ANALOGY WITH THE BELGIAN BEDS. RUSSIA. EXTENSION OF THE MIOCENE STRATA TO THE CASPIAN SEA. ITALY. GREAT DEVELOPMENT OF THE MIOCENE. GREECE. BONE-BEDS OF PIKERMI. GAUDRY'S RESEARCHES. VARIED RELATION OF THE FAUNA. MALTA. WESTERN ASIA AND EGYPT. FOSSIL FOREST NEAR CAIRO. PERSIA. MARAGHA BONE-BED. INDIA. SIWALIK MAMMALIA. DR. FALCONER'S DISCOVERIES. CONTESTED AGE OF THE BEDS. AUSTRALIA AND NEW ZEALAND. NORTH AMERICA. THE ATLANTIC AND PACIFIC STATES. MAMMALIA OF THE FRESH-WATER BASINS. GREENLAND. GRINNELL LAND. SPITZBERGEN. QUESTIONED AGE OF THE PLANT-BEDS.

England. If we have to relegate the leaf-beds of Bovey Tracey, Mull, and Antrim to the Oligocene or other older series, there remains no representative of Miocene strata in Britain, unless, when the fauna of the Lenham and St. Erth beds are more exactly determined, those isolated deposits should prove to be older than the Pliocene, with which I have provisionally placed them. We have, therefore, now only to deal with the foreign Miocenes. For the reasons mentioned in the last chapter, some uncertainty still attaches not only to the divisional lines between the Upper Eocene and the Oligocene, but also to those between the Oligocene and the Lower Miocene, so that the lines here adopted may hereafter be liable to further modification.

Belgium. The Belgian geologists consider that the unfossiliferous fine white sands of Bolderberg, overlying the Rupelian, are of late Oligocene age, but whether the overlying fossiliferous grits, with their silicified shells (often very fragmentary), should also be referred to the same series (Mourlon's 'Géologie de Belgique'), may be thought more doubtful.

Dumont grouped these Bolderberg beds with the Diestian, and Lyell with the Miocene.

The high-level Diestian beds consist mainly of ferruginous sands and sandstone often full of small flint-pebbles. They form a thin deposit, capping the surface of the Tertiary and Chalk hills in Flanders, on the borders of France and Belgium. It is fossiliferous only in places, and the fossils are always in the state of ferruginous casts and impressions. Amongst them are *Terebratula grandis*, with species of Isocardia, Ringicula, Turritella, Tellina, etc.

The Belgian geologists correlate these ferruginous beds with the sands overlying Rupelian strata, and underlying the Crag (*Scaldesian*) beds, around Antwerp. They were formerly known as the Edeghem beds, and are now divided into—(1) a lower bed of grey sands (*Sables à Panopæa Menardi*), containing a large number of fossils, amongst which are *Isocardia lunulata*, *Cardita intermedia*, *Arca latisulcata*, *Ancillaria obsoleta*, *Conus Dujardini*, *Pleurotoma interrupta*, *Turbinolia appendiculata*, etc. To these succeed—(2) an upper bed of dark green sands, containing an enormous number of *Pectunculus pilosus* (*Sables à P. pilosus*), together with *Ostrea navicularis*, *Cardium subturgidum*, *Arca Diluvii*, *Turritella subangulata*, *Pyrula condita*, *Stephanophyllia Nysti*, etc. Bones are rare in the lower of these beds, but remains of Ziphioid Cetaceans, Carcharodon (*C. megalodon*, Fig. 205), Squalodon (*S. Antwerpiensis*), etc., often abound in the upper bed No. 2. Some geologists, considering these as passage-beds, have proposed to term them Mio-pliocene[1]. They form the *Anversian System* of M. Cogels.

France. There are no Miocene strata in the Paris Basin; but they set in over the 'Calcaire de Beauce' in the neighbourhood of Orleans, and extend thence into Touraine. They appear again, in small and isolated patches, in the West and South of France. As the sea retired from the North of the French area, it left in the West and South a number of small gulfs, in which lived multitudes of littoral and shallow-water shells, while herds of novel Mammalia lived on the enlarged lands.

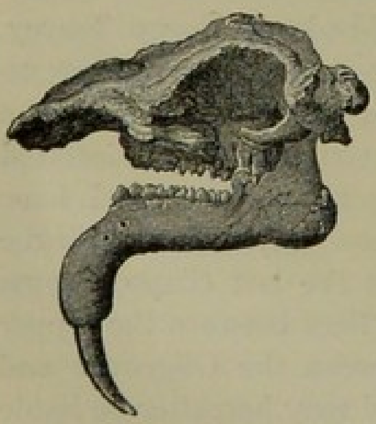

FIG. 197. *Dinotherium giganteum*, Kaup.

To the sands of the 'Orléannais' succeed the unfossiliferous clays and sands of Sologne; and then the well-known rich shell-beds,—the Faluns of the Touraine. Just as the mammalian fauna of the Oligocene period is characterised by its special Pachyderms, so

[1] In a recent paper (1885), Von Koenen places these beds, together with the Sandstones of Bokup, Reinbeck, and elsewhere in North Germany, nearly at the top of the Miocene.

that of the Miocene period is distinguished by its characteristic Proboscideans and Quadrumana. Peculiar species of Mastodon, Dinotherium, Dicroceras, Anchitherium, Hipparion, and Catarrhine Apes give a stamp to the fauna of this period.

The Faluns of the Touraine[1] and of Brittany[2] consist, like our Crags, of calcareous sands abounding with shells,—many broken, worn, and comminuted, and others in an admirable state of preservation. These beds are well seen in the neighbourhood of Pontlevoy and of Manthelan. Of the shells, the following are amongst the most common and characteristic:—

Crassatella concentrica, *Duj.*
Cardita crassa, *Lam.*
Pectunculus pilosus, *Linn.*
Pecten substriatus, *D'Orb.*
Lucina columbella, *Lam.*
Corbula carinata, *Duj.*
Pholas dimidiatus, *Duj.*
Cypræa globosa, *Duj.*
Ancillaria glandiformis, *Lam*
Cerithium lignitarium, *Eichw.*
" Serresii, *D'Orb.* Fig. 198, *b.*
Conus Dujardini, *Desh.*
Trochus miocænicus, *Mayer.*
Voluta Lamberti, *Sby. var.*
(V. miocænica, *Fisch.*)

According to the recent researches the Molluscan fauna of the Faluns, including that of the Anjou beds, consists of 647 species, of which 155, or 23 per cent., are still living. It is, however, well to note that the relative proportions of the different orders vary very considerably, as shown in the following table:—

	No. of species.	Living species.	Per cent.
Brachiopods	4	0	0
Lamellibranchs	215	70	32
Holostomatous Gasteropods	221	56	25
Siphonostomatous Gasteropods	207	29	14
	647	155	24

Northern species are absent; British species are rare; while there are a large number of Mediterranean species, and of others which now live on the West Coast of Africa (Senegal) and around the Azores and Canary Islands; species of the peculiar genera *Amathina* and *Mitrularia* now live on the shores of Madeira and Cape Verde.

The remains of Dinotherium (Fig. 197), together with those of Mastodon, Anthracotherium, Hippopotamus, and several species of Deer, are of common occurrence at Pontlevoy, but they are derived in part from the underlying sands of the Orléannais, in which species of Rhinoceros, Amphicyon, and Anchitherium also occur.

An upper division of the Faluns forms small outliers in Anjou and

[1] Dujardin, in 'Mém. Soc. Géol. de France,' vol. ii. p. 211; Lyell, 'Proceed. Geol. Soc.,' vol. iii. p. 437; Domville, 'Bull. Soc. Géol. de France,' 3e sér., vol. vii. p. 56; Dollfus and Danzenberg, 'Coquilles Fossiles des Faluns de la Touraine.'

[2] Lyell, *Op. cit.*; Tournoüer, 'Bull. Soc. Géol. de France,' 2e sér., vol. xxv. p. 367; Vasseur, 'Terrains Tertiaires de la France Occidentale.'

Brittany. Near Doué it forms a soft rock, consisting largely of comminuted shells and Polyzoa, with much false-bedding, so that it closely resembles in general aspect the semi-consolidated polyzoan sand-beds of the White (Coralline) Crag of the neighbourhood of Gedgrave and Orford. This division contains also a large Terebratula (*T. perforata*, Defr. = *T. grandis*, Blum. ?), and a characteristic Oyster (*Ostrea crassissima*, Lam.), together with bones of Halitherium (*H. medium*, Cuv.), of more than one species of Whale, teeth of Carcharodon (*C. megalodon* and *C. angustidens*, Fig. 199), and of Oxyrhina (*O. xiphodon*), etc., and a peculiar calcareous sea-weed, the Lithothalmium.

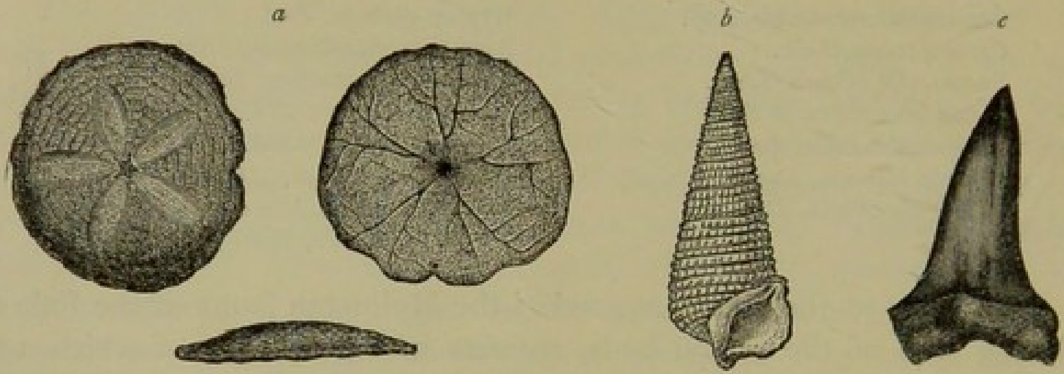

FIG. 198. Miocene (Faluns) Fossils.
a. Scutella subrotunda, Lam. *b. Cerithium Serresii*, D'Orb. *c. Tooth of Oxyrhina Xiphodon.*

M. Tournoüer considers that the shell-bed of St. George de Bohun, referred by Lyell to the Red Crag, belongs to this upper division of the Faluns [1].

In the neighbourhood of Bordeaux [2] the *Falun of Merignac* rests upon a surface of fresh-water limestone of Oligocene age, drilled by boring shells. The rich Faluns of Léognan and Saucats, which occupy a rather higher position, are the equivalent of the Faluns of Touraine. The most abundant fossils of these Bordelais beds are *Terebra Basteroti*, *Murex Turonensis*, *Cerithium Serresii*, *C. lignitarium*, *Lucina columbella*, etc., with a characteristic Echinoderm (*Scutella subrotunda*, Fig. 198, *a*) and teeth of *Carcharodon megalodon*, etc. The Falun of Salles constitutes an upper zone with *Cardita Jouanneti*, *Nassa prismatica*, etc. On the same horizon *Ostrea crassissima* is met with.

At Simorre, and elsewhere in the South of France, the *Mastodon angustidens* (Fig. 199) is a common and characteristic species of the Miocene Proboscideans.

In the Agenais the Lower Miocene consists of fresh-water marls and limestones. They form, according to Victor Raulin, a well-marked geological horizon, and are characterised by *Planorbis subpyrenecanus*, *Limnæa Larteti*, *Helix Agenensis*, etc. To these succeed the fresh-water

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[1] See also Alfred Bell, in 'Geol. Mag.' for May, 1872, p. 210.

[2] See various papers by Victor Raulin, Delbos, Basterot, Gaudeloupe, and others.

beds of Armagnac with *Limnæa Laurillardiana*, *Planorbis Goussardianus*, *Helix Sansaniensis*, and *Clausilia maxima*.

On this latter horizon, in the Department of Gers, the calcareous beds of Sansan occur, so celebrated for their mammalian and other vertebrate

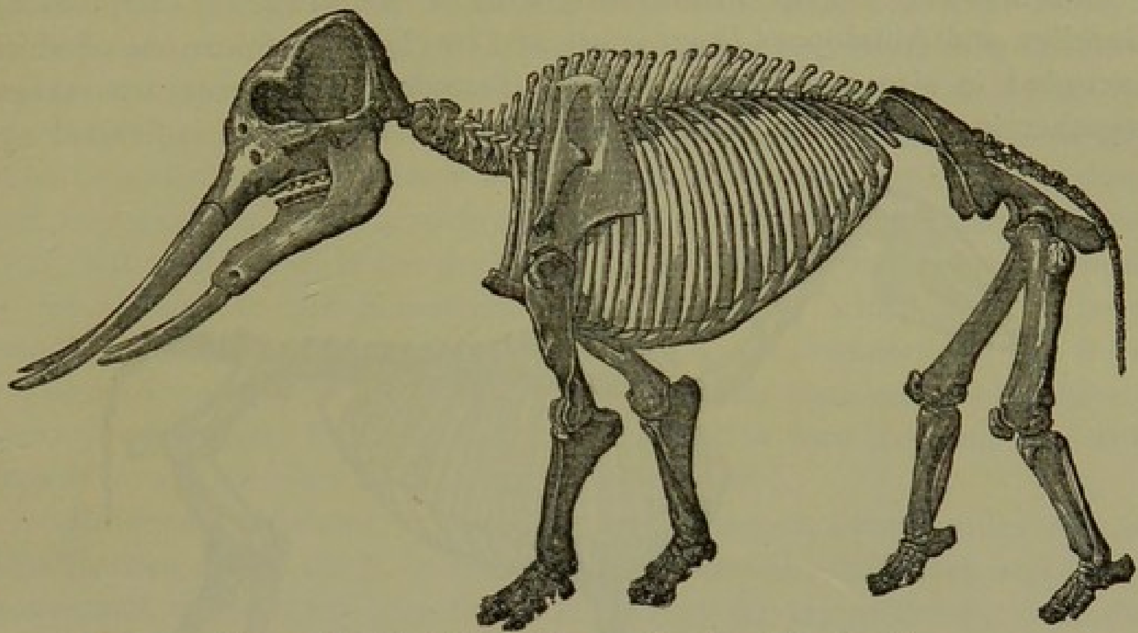

FIG. 199. *Mastodon* (*Trilophodon*) *angustidens*, Cuv. (After Gaudy.)

remains. These have been described by M. E. Lartet, according to whom this fauna includes one Quadrumane, ten Insectivores, twenty-one Carnivores, thirteen Rodents, eleven Ungulates, eight Proboscideans, eight Ruminants, and one Edentate, together with numerous Birds, seven Chelonians, nine Saurians, two Serpents, and nine Batrachians. The following are some of the species of this remarkable assemblage :—

Protopithecus antiquus, *Blainv.*
Amphicyon major, *Blainv.*
Hemicyon Sansaniensis, *Lart.*
Felis hyænoides, *Lart.*
Dicroceras elegans, *Lart.* Fig. 212, *a*.
Macrotherium Sansaniense, *Lart.*
Mastodon tapiroides, *Cuv.*
Acrotherium incisivum, *Cuv.*
Dinotherium giganteum, *Kaup.* Fig. 197.

The associated Mollusca are of land and fresh-water species (Helix, Pupa, Cyclostoma, Planorbis, Limnæa, etc.).

The Quadrumana are represented by an anthropomorphous Ape of small size, allied to the Gibbons.

In Auvergne, the Oligocene strata are succeeded in the neighbourhood of Mont Dore by light-coloured Miocene marls, with a flora of Glyptostrobus, Sequoia, Liquidambar, etc., denoting, according to M. De Saporta, a hot damp climate with warm winters. At St. Géraud there is a mammalian fauna very similar to that of Sansan ; and at Aurillac there are gravelly beds resting on basalt and containing remains of *Dinotherium giganteum*, *Hipparion gracile*, *Machairodus cultridens*, etc. ; while at Aubignas an old alluvium, with remains of *Rhinoceros Schleiermacheri*, *Hipparion gracile*, *Machairodus*, and *Ictitherium*, underlies a mass of basalt.

Another local deposit of this age and character is that of Mount Léberon, in Vaucluse. It has been described by MM. Gaudry and Gervais. The former records the occurrence of *Hyæna eximia*, *Ictitherium hipparionum*, *Machairodus cultridens*, *Dinotherium giganteum*, *Rhinoceros Schleiermacheri*, *Cervus Matheronis*, with a multitude of Hipparions, Gazelles, and Antelopes (*Tragoceras*), and two land Tortoises, one of which exceeded in size any European fossil Testudo. The bones are massed together in a fine loam, which, with the circumstances of individual age

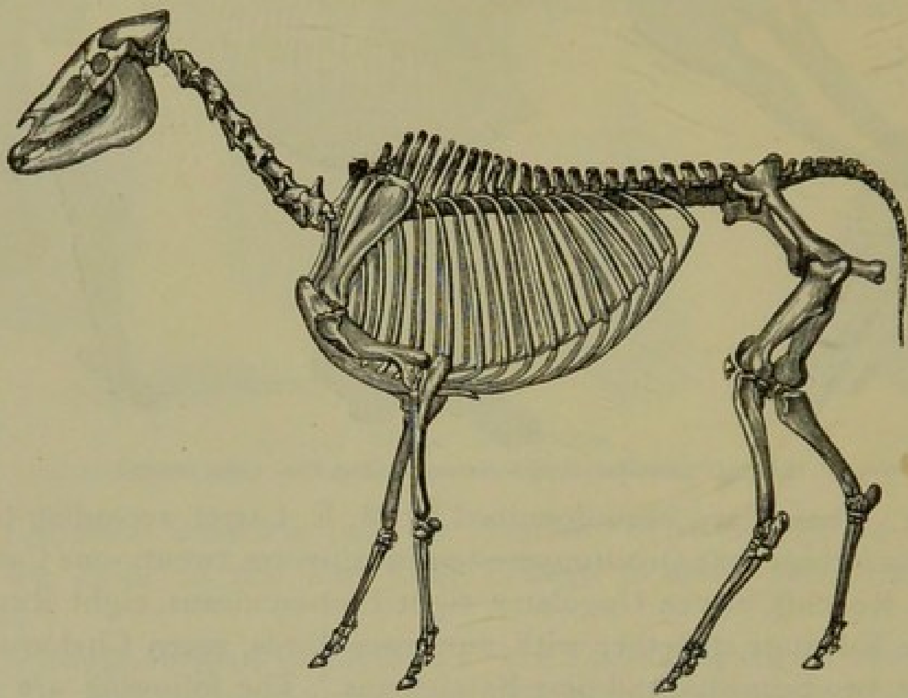

FIG. 200. *Hipparion gracile* (as restored by Gaudry), $\frac{1}{20}$.

and the rarity of Carnivora, leads M. Gaudry to suppose that the animals were drowned during floods, and their remains thrown together rapidly and irregularly on the sides of the old valley. Beds of this age are met with also in the valley of the Rhone[1].

Spain, Portugal, etc. Miocene beds with *Ostrea crassissima* and *Turritella rotifera* occur on the coast near Barcelona and further south; while fresh-water beds of this age occupy parts of Central Spain. In the valley of the Tagus they form thick beds rich in Pectens and Polyzoa, described by D. Sharpe and Pereira da Costa. Miocene beds again occur in Madeira and the Azores.

The Miocene (Upper Molasse series) Strata of Switzerland have been described by A. Favre, Heer, Mayer, and others. The Molluscan fauna comprises 658 species, of which, according to Dollfus, 207 or 31 per cent. are living species. The series consists of a lower fresh-water

[1] For these see the papers of MM. Paul de Rouville, Matheron, Fischer, Tournoüer, and others.

division (Mayencian), succeeded by marine and fluvio-marine strata (Helvetian), and these again by a land and fresh-water group (Tortonian).

The lower division contains remains of Palms, Fig-trees, Acacias, Pines, etc., with Anthracotherium, Rhinoceros, and Crocodile. In the higher fluvio-marine series of St. Gall are beds containing *Auricula oblonga, Bythinia acutens* and a small flora, together with others containing *Cardium hispidum*, *Chama gryphina*, *Ostrea crassissima*, and other marine shells.

The Upper Miocene of Œningen has long been celebrated for the variety of its organic remains and their wonderful state of preservation. We there find a profusion of objects, such as, from their soft and fragile nature, have rarely left their record in the geological series. In this respect this deposit is only second to the Solenhofen beds; while, in addition to a large vertebrate and invertebrate fauna, Œningen has a wonderfully rich flora, the whole forming a picture of the land-life of the time such as has rarely come down to us. For an admirable description and discussion of this deposit we are indebted to the late Professor Heer [1].

Œningen is situated on the Lake of Constance, twelve miles east of Schaffhausen. The strata consist of light-coloured sandstones, soft limestones, and marls, often very finely laminated, having evidently been deposited in the deep and tranquil waters of a lake. It is between the thin laminæ of these beds that the innumerable tender invertebrates and plants are preserved. Heer's list includes 826 species of Insects, twenty-eight Spiders, seven Crustaceans, four Mollusca, thirty-two fresh-water Fishes, twelve Amphibians and Reptiles, six Birds, six Mammals, and 475 Plants.

Whereas in the Upper Oligocene (Aquitanian) of Switzerland, evergreen trees constitute nearly three-fourths of the whole flora, in the Upper Miocene (Œningian) they do not constitute more than half the number of species, woody plants with deciduous leaves having become much more numerous. Palms also, which occupy so important a position in the former, now become rare. Australian and tropical forms of plants are also less numerous, their place being taken by Mediterranean and North-American forms of vegetation. Amongst the more characteristic plants of the Œningen beds are,—

Populus mutabilis, *Heer*.
Laurus princeps, *Heer*.
Carpinus pyramidalis,
Podogonium Knorri, *Al. Br.* Fig. 201, *b*.
Liquidambar Europæum, *Al. Br.* Fig. 201, *a*.
Planera Ungeri, *Ett.* Fig. 201, *b*.
Cinnamomum Scheuchzeri, *Heer*. Fig. 201, *c*.
Glyptostrobus Europæus, *Heer*. Fig. 201, *d*.
Taxodium distichum-miocænum, *Heer*. Fig. 201, *e*.
Comptonia mirabilis, *Brong*.

Taxodia, *Glyptostrobi*, Camphor-trees, and Tulip-trees were then widely spread over the European area. Marsh- and water-plants were also

[1] 'Flora Tertiaria Helvetiæ;' 'Die Insektenfauna von Œningen, etc.;' 'Die Urwelt der Schweitz.' The last work, which has been translated into French and English, gives an excellent account of the geological history of Switzerland. The above summary is from the English Edition.

widely dispersed; and just as at the present day Oaks, Poplars, and Maples are subject to the attacks of numerous Fungi, so were the trees of the Œningen forests invaded by some twelve species of those parasites. Amongst the Ferns there was a Pteris very nearly allied to the common

FIG. 201.—Upper-Miocene Plants, Œningen. (After Saporta and Heer.)
a. Liquidambar Europæum, Al. Br. *b. Planera Ungeri*, Ett. *c. Cinnamomum Scheuchzeri*, Heer. *d. Glyptostrobus Europæus*, Br. *e. Taxodium distichum-miocænum*, Heer. *f. Podogonium Knorri*, Ad. Br.

Swiss bracken; while three other species find their nearest representatives in more southern forms.

The *Glyptostrobus Europæus* formed bushy trees like the *G. heterophyllus* of Japan and China, which is now confined to Eastern Asia; while the *Taxodium distichum-miocænum* is closely analogous to the Swamp-cypress of the Southern United States and of Mexico.

Grasses and reeds were abundant, and Sarsaparillas (*Smilax*) formed evergreen climbing plants in these Miocene forests. The *Calamopsis Bredana* of Œningen belongs to the group of the Rotang Palms of tropical Asia; while the Liquidambar is so nearly allied to a North-American species that probably it is to be regarded only as a variety. The Poplars mostly resembled the existing black poplars and the aspens; one species, however, was allied to the American balsam-poplar. The Oaks, which were very numerous, were almost without exception of leathery-leaved species, such as now occur in Mediterranean and American countries; but the Alder and Birches were more similar to the existing Swiss forms. The Cinnamon trees were all Asiatic forms; but the Laurels resembled the Southern-European species. The latter seem to have formed large evergreen forest trees.

Sandal-wood trees are also represented at Œningen, together with species of Proteaceæ, both of Australian affinities. On the other hand, the Vaccinieæ are mostly allied to existing South-European forms. There were also Ash, Lime, and Walnut trees, Convolvulaceæ, Bignoniæ, Ivies, Dogwoods, Myrtles, Rhamneæ, Celastrineæ, Hollies, and Gleditschiæ; while the existing Tamarinds are represented by the extinct *Podogonium*.

Thus the facies of the Miocene flora presents a very general resemblance to some of the floras of the present day; and the species, though distinct, often exhibit differences so small that it may be considered doubtful whether they are sufficient to establish limits for specific separation. On the whole, the relations of this flora are mainly with the flora of the Southern States of North America, and of the Mediterranean area.

The Spiders of Œningen exhibit only one extinct genus. The others differ little apparently from living genera that have a wide distribution. With one exception, which represents the existing Swiss water-spiders, they probably all lived on land.

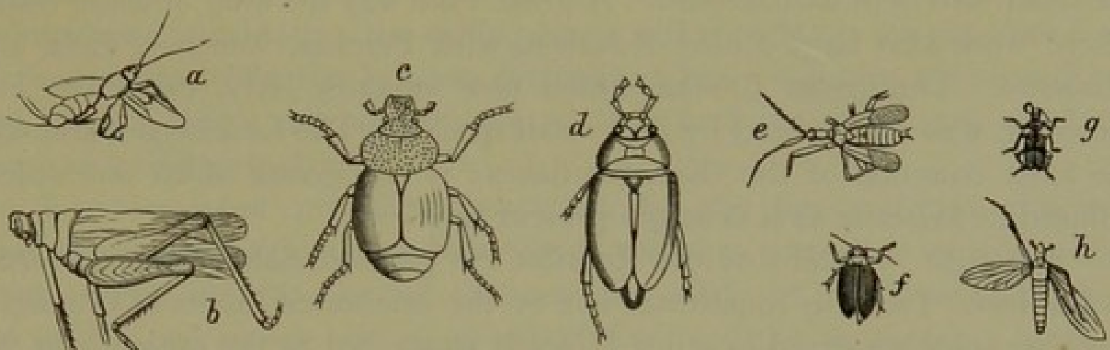

FIG. 202. Miocene Insects, Œningen. (After Heer.)
a. *Ichneumon infernalis*, Heer. b. *Œdipoda Fischeri*, Heer. c. *Trichius ædilis*, Heer. d. *Hydrous Escheri*, Heer. e. *Harpactor maculipes*, H. f. *Galleruca Buchi*, H. g. *Telephorus macilentus*, H. h. *Plecia hilaris*, H.

Of the Insects there are 543 species of Beetles, 22 Orthoptera, 29 Neuroptera, 81 Hymenoptera, 3 Lepidoptera, 64 Diptera, and 136 Hemiptera and others. The greater part belong to existing genera; there are, however, forty-four peculiar genera, including one hundred and forty species. A great number of wood-eating insects are found. After the beetles,—ants, gnats, and midges occur most abundantly. They are so perfectly preserved in the fine calcareous sediment that the hairs on their legs and wings can be seen under the microscope, and the colour on the wings of some of the Coleoptera is still fresh and varied. Water-beetles are numerous and of large size. There were also Cockroaches, Ladybirds, Grasshoppers, Dragon-flies, May-flies, and Crickets. The Blister-beetles and many of the other families of Beetles are likewise present.

Besides these, Bees, Wasps, Aphides, and various Flies are represented. Of the Bibionidæ, which include the blood-sucking flies, there are sixteen species, the greater number resembling European, and others North-

American forms; while one fly (*Plecia*) is now confined to South America and the Cape of Good Hope. Of the Lepidoptera traces only of three species have been met with.

On the whole, the Insect-fauna of Œningen has more of a Mediterranean character and less of a southern and American stamp than the flora. Heer (vol. ii, pp. 12–56) remarked that the great predominence of the Reduviini, Scutati, and Coreodes, the presence of large Cicadidæ, of large species of Cercopidæ, together with the gigantic Water-bugs and the Rhynchota, furnish evidence of a warmer climate, and especially of milder winters than now prevail in Central Europe.

Of the Decapod Crustaceans, there is one fresh-water Prawn, very much like the existing *Palæmon fluviatilis*, and two Crabs. One of these is a river-crab of the common South European type, and the other a land-crab quite foreign to the European fauna.

Of the fifteen genera of Fishes, only one, allied to the Carps, is extinct; twenty-five species belong to twelve genera still existing in the fresh-waters of Switzerland. A great Pike was the king of these fishes. There were also large-scaled Roaches, with Perches, Tenches, Eels, and Minnows. The genus Lebias, which now inhabits Italy, the East, and America, was represented by four small species. The Leuciscus is amongst the most common of the Œningen fishes: it is a genus which was widely diffused in Miocene as it is at the present time.

Amongst Amphibians and Reptiles the gigantic Salamander (*Andrias Scheuchzeri*, Tschudi) constitutes one of the celebrated fossils of Œningen. Another species existed in other Miocene strata, but at the present day this type of animal is altogether wanting in Europe. The nearest living species occur in Japan and in North America. There was likewise a gigantic Frog nearly allied to the horned frog of Brazil, three Toads, and three Snakes. Crocodiles also inhabited the Swiss rivers and lakes, though they seem to have been of small size. Of the Tortoises there were several species, belonging to genera which keep almost entirely to the warm and torrid zones of the Old and New Worlds. The alligator-tortoise of Œningen was a foot and a-half long, and is one of the most striking American forms of the Swiss Miocene land.

Several undoubted remains of Birds have been found, belonging, according to H. von Meyer, to six species, but only one—an aquatic bird of the family Anatidæ, a little smaller than the existing wild goose—has yet been well determined.

The Upper-Miocene mammalian fauna, with its numerous Pachyderms and Ruminants, forms a remarkable group. The *Mastodon tapiroides* is found at Œningen, the *Dinotherium giganteum* at Delsberg. Of Rhinoceroses there were several species, including *R.* (Acerotherium) *incisivus*, Cuv. The *Anchitherium aurelianense*, *Hipparion gracile*, and *Hyotherium Sœmmeringi* occur in the Upper Miocene of Elgg. There were also several Deer, a Squirrel, and two Hares. The Carnivores are represented by Hyænælurus, Hyænodon, Amphicyon, and Galecynus; and the Quadrumana by the Pliopithecus—a Catarrhine Ape apparently of the same species as that of Sansan.

To complete the picture of this Miocene landscape, Heer observes that the herbs and grasses formed a luxuriant vegetation in which the deer, musk-deer, and the horses of those times found ample nourishment. Oak forests, for the most part composed of evergreen trees, furnished fruits throughout a great part of the year, which, with the fruits of many other trees, such as figs, myrtles, jujubes, whitethorns, walnuts, and numerous Papilionaceæ, might have served as food for the many swine-like animals which then lived. The fleshy rhizomes of Nymphæa and Nelumbia, the Irises, the knotty roots of the Cyperaceæ and other marsh-plants, furnished the Miocene Tapirs and Rhinoceroses with food of the same nature as that afforded by corresponding living plants to their representatives of the present day. Squirrels found an ample provision of pine- and fir-cones, walnuts, and hazel-nuts ; the calling-hares and chinchillas sought their food in the woods, while the beavers established their colonies where willows and birches, alders and poplars, offered their bark for sustenance and their stems as building-materials.

For the Apes, provision was made by the figs, walnuts, almonds, jujube-trees, date-palms, and bread-trees, together with the rice and millet plants which already clothed the ground; while the various animals of the prairie and plains offered abundant food for the carnivorous hyæna-, civet-, and tiger-like animals which haunted the forests and caves of this Miocene land.

Œningen and the marls of Schrotzburg also furnished Heer with special data as to the climate and the course of the seasons. Plants, as is well known, are dependent on the seasons for the constantly recurring cycle of their development, this influence affecting some plants more than others. After an elaborate inquiry as to the probable date of flowering of the Œningen trees, the temperature needed for the maturing of their fruit, the limitations caused by cold and by heat, and various other points, Heer sums up all the data afforded by the flora, and concludes that the Swiss lands in the Later Miocene times had a climate resembling that of Madeira, Malaga, Sicily, Southern Japan, and New Georgia, with an annual mean temperature of 64° to 66° Fahr., or about 16° Fahr. above that of the present day. At the same time, similar evidence indicates that between the end of the Oligocene and the end of the Miocene period, there was a gradual diminution of temperature, the fall in the interval being equal to about 4° Fahr.

South Germany. The marine sands and the Cyrena-marls of the

Mayence Basin are overlain by Littorinella- and Cerithium-limestones, to which succeed ossiferous sands. The fresh-water limestone, with *Littorinella acuta*, Desh., *Planorbis parvulus*, Reuss, *Limnæa Thomæi*, Reuss, *Cerithium cinctum*, Lam., *C. Rahtii*, etc., is remarkable for the very large proportion of land shells which it contains. Of Helix there are twenty-four species, Pupa thirteen, and Cyclostoma three. The *H. Ramondi* is characteristic. There are also a variety of Batrachians, a Salamander, five Rodents, three Carnivores, etc. Where the limestone passes into more brackish-water conditions, species of Cerithium predominate, with *Mytilus Faujasi*, etc. Sandberger has shown that the land and fresh-water shells have their present representatives in the Mediterranean Basin; while a few species (*Helix pulchella*, *Pupa palustris*, etc.) are still living in other parts of Europe. With these are associated plants, including species of Cinnamomum, Magnolia, Acacia, Figs, Evergreen Oaks, Pines, and Cypresses.

The overlying sands contain the typical Miocene Mammalia. It was at Eppelsheim that Kaup made his great discovery of the skull of the gigantic Dinotherium (Fig. 197), the characteristic Miocene Proboscidean. There he also found and described *Tapirus priscus*, *Rhinoceros Schleiermacheri*, *Mastodon longirostris*, *Machairodus cultridens*, *Hipparion* (*Hippotherium*) *gracile*, with other of the animals common to Œningen and Sansan[1], such as *Aceratherium incisivum*, Cuv., and the *Rhinoceros*.

The Vienna Basin has at its base a series of fluvio-marine strata, the equivalent of the upper part of the Aquitanian, succeeded by marine sands of the Middle Miocene (Mayencian and Helvetian), which are overlain by another fluvio-marine and fresh-water series. This is sometimes referred to the Pliocene; but, as the general characters of the fossils, apart from the introduction of some new species, is alike throughout, the grouping of the whole of the series with the Miocene seems the preferable classification.

The lower of these divisions contains *Cerithium margaritaceum*, with *Mastodon* and *Dinotherium*. The marine series is composed of sands, pebble-beds and marls, succeeded by a peculiar calcareous freestone (Leithakalk) formed of the débris of shells, Foraminifera, and Nullipores. The fossils, which are very numerous (over 1000 species), are of a Mediterranean or Southern type. Amongst them are *Arca diluvii*, *Pectunculus pilosus*, *Tellina strigosa*, *Pecten latissimus*, *Panopæa Menardi*, *Cerithium pictum*, etc.[2] The fossils of the upper or Sarmatian division are of a more Northern type. The lower beds consist of thick sands, containing *Cerithium pictum* in abundance. To these succeed sandstones, clays, and a peculiar grey micaceous marl termed 'Tegel,' containing species of Cardium,

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[1] Hamilton, *Op. cit.* 285; F. Sandberger, 'Die Conchylien der Mainzer Tertiärbecken.'

[2] See Hörne's 'Die Fossilen Mollusken der Tertiärbecken von Wien.'

Rissoa, Melanopsis, Helix, Valvata, and a curious fresh-water genus, Congeria (*C. subglobosa*), whence the term 'Couches à Congeries.' They also contain a Mammalian fauna and a flora analogous to those of Œningen and Eppelsheim, including *Hipparion gracile*, *Acerotherium incisivum*, *Mastodon longirostris*, *Rhinoceros Schleiermacheri*, etc., with *Salix augusta*, *Glyptostrobus Œningensis*, *Juglans latifolia*, etc.

The Sarmatian series extends thence down the valley of the Danube, through Hungary and Transylvania, to the Carpathians, with a group of marine fossils similar to those of the Vienna Basin. In places, this series contains subordinate beds of anhydrite, gypsum, and rock-salt. At Wieliczka, the salt beds attain great dimensions, and are largely worked.

German geologists have introduced the term *Neogene*, to include the Miocene and Pliocene, the break between which is, in some parts of Europe, very difficult to fix; while the fauna and flora indicate a change of conditions and of temperature in marked contrast to the higher temperature which prevailed during the Palæogene, or Eocene and Oligocene periods.

Northern Germany. Upper-Miocene strata extend over large tracts in Mecklenburg, Hanover, and Westphalia, constituting the Sands of Stettin, and the Sandstones of Holstein, Bokup, Melbeck, and Bersenbrück. The Mollusca have been described by Von Koenen; amongst others are *Arca diluvii*, *Leda pygmæa*, and other species common to the Belgian beds. The lower stages appear to be wanting[1].

Russia. Strata of Miocene age occur in Volhynia and Podolia, and are prolonged thence towards the Caspian. They contain a fauna very similar to that of the Vienna Basin, together with a few species now living in the Caspian Sea.

Italy. In the plains at the foot of the Alps, and extending thence to the Ligurian Alps, Miocene strata are largely developed. They consist of marls, soft sandstones, and conglomerates, from 10,000 to 12,000 feet thick, and in places very fossiliferous. The lower marls abound in Pteropods, and the upper in Pleurotomæ. Near Turin the Middle Miocene contains a rich fauna analogous to that of the Faluns of Touraine and of Bordeaux. Beds of this age occur also in the neighbourhood of Rome, in South Italy, and in Sicily[2].

Miocene strata are developed in Algeria and the Transylvanian provinces, retaining a few of the species found in more northern districts.

Greece. But the Miocene locality of greatest interest, and requiring fuller notice, is that of Pikermi in Greece, where the important researches of M. Gaudry brought to light a remarkable Mammalian fauna, intermediate in its forms between European, Asiatic, and African types.

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[1] For further information the reader should consult the works of Beyrich and Von Koenen, especially the 'Das Miocän Nord-Deutschlands' of the latter.

[2] See papers by Stoppani and Seguenza.

This fresh-water deposit, which is considered by M. Gaudry[1] to belong to the Upper-Miocene stage, contains amongst other remains those of—

Mastodon Pentelici, *Gaudry*.
Dinotherium giganteum, *Kaup*. Fig. 197.
Rhinoceros Schleiermacheri, *Kaup*.
Aceratherium (Rhinoceros) incisivum, *Kaup*.
Chalicotherium modicum, *Gaudry*.
Hipparion gracile, *Gaudry*. Fig. 200.
Tragoceras amaltheus, *Gaudry*.
Dremotherium.
Ictitherium robustum, *Gaudry*. Fig. 203.
Helladotherium Duvernoyi, *Gaudry*.

The Mastodon has the same peculiar physiognomy as the *M. longirostris* of Eppelsheim, though there are differences which may constitute a distinct species. Chalicotherium is a genus occurring in the Oligocene of Quercy and the Miocene of America; Tragoceras occurs in the Miocene of Mont Léberon; and Dremotherium in the Miocene of St. Géraud. The Ictitherium was a peculiar animal, related both to the Hyænas and

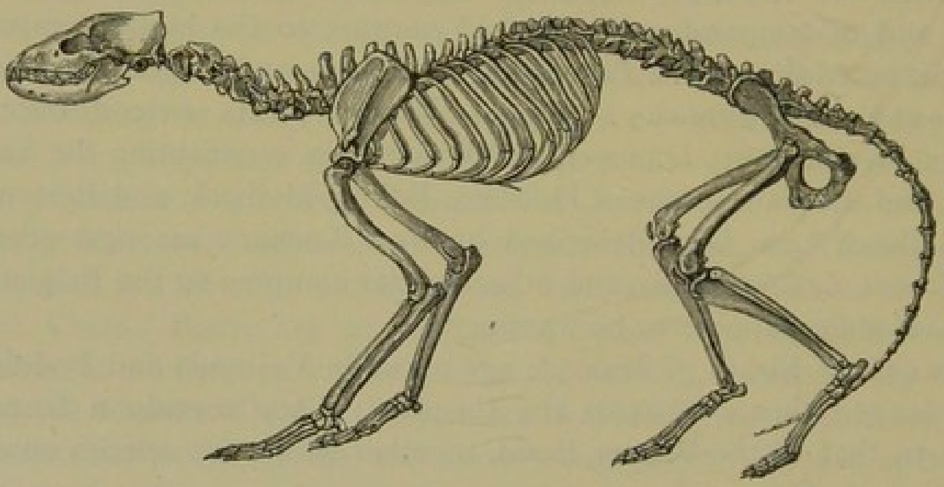

Fig. 203. *Ictitherium robustum* (as restored by Gaudry), ⅛.

Civets; and the Helladotherium a large animal allied on one side to the Giraffes, and on another to the Antelopes, but having no horns. Its remains are found in France, Greece, and India. Species of Giraffe (*Cameleopardis attica*) are also found at Pikermi. The same genus occurs in the Siwalik hills.

The *Dinotherium giganteum*, *Hipparion gracile*, *Rhinoceros Schleiermacheri*, and *Aceratherium incisivum* are characteristic Miocene species of Western Europe.

There has also been found at Pikermi a large Monkey (*Mesopithecus Pentelici*), intermediate in its characters between the living Semnopithecus and Macacus.

M. Gaudry[2] points out how difficult it is to conceive that these herds of Antelopes with curious horns, of Hipparions, heavy Rhinoceroses,

[1] 'Animaux fossiles et Géologie de l'Attique.'

[2] 'Les Enchainements du Monde Animal, Mammifères Tertiaires,' p. 258; and 'Bull. Soc. Géol. de France,' 3me Sér., vol. xiii. p. 287.

and enormous Wild-boars, of the gigantic Helladotheria, Dinotheria, and Mastodons, could have lived on a land with the configuration which Greece now has; he supposes that at that time the islands did not exist as an

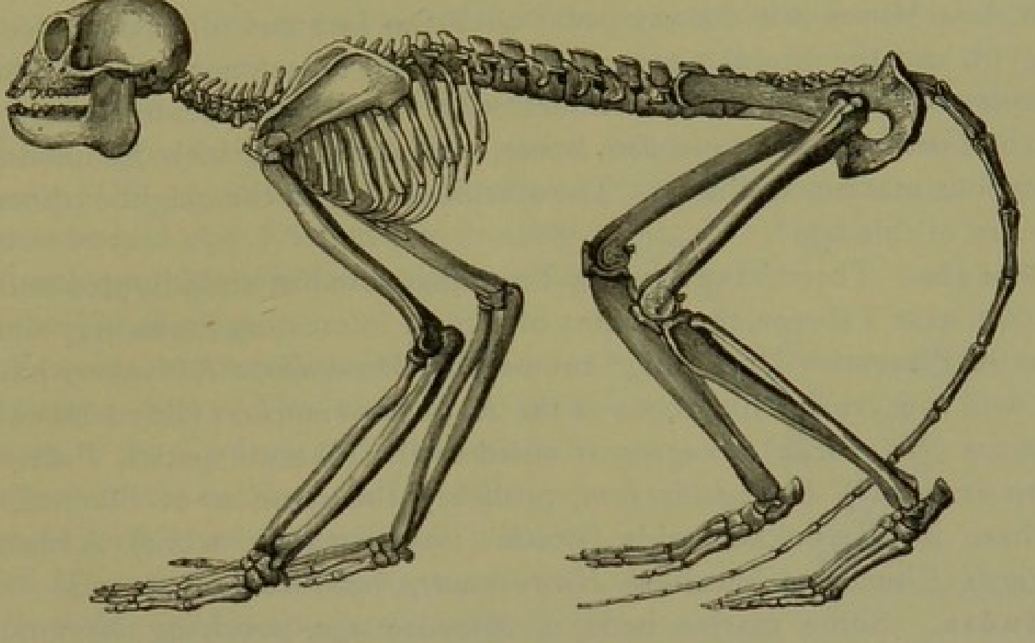

FIG. 204. *Mesopithecus Pentelici* (as restored by Gaudry), $\frac{1}{5}$.

archipelago, but that great plains, on which these animals flourished, extended from Mount Pentelicus to the shore of Asia Minor, and that thus the continuity of life from Western Europe to Eastern Asia was maintained. In proof of this he shows that those elevated plains subsequently underwent a subsidence, which submerged the land and brought over it the waters of the Pliocene sea, of which the Molluscan fauna is now found, on approaching the sea at Raphina, in beds newer than the Pikermi deposit.

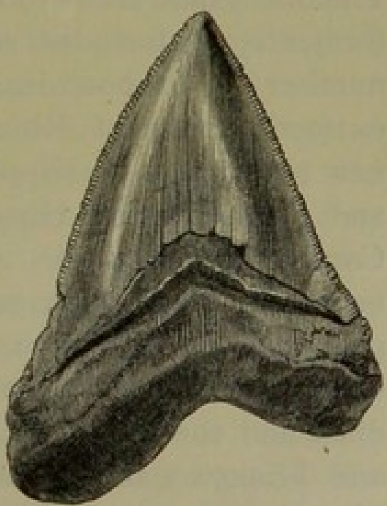

FIG. 205. *Carcharodon megalodon*, Ag. (Malta), $\frac{1}{2}$.

Malta. The geological formation of this island—described by Admiral Spratt[1], the late Dr. Leith Adams, and others—consists almost entirely of Miocene strata, composed chiefly of fossiliferous light-coloured limestones and freestones with marine Mollusca, often in the state of casts, and crowded in some parts with Foraminifera. Some beds are composed largely of Polyzoa and Nullipores. The notable fossils are the numerous Sharks' teeth especially those of the great *Carcharodon megalodon*, and abundant Echinoideæ;—*Spatangus pustulosus*, *Amblypygus Melitensis*, *Cidaris Adamsi*, *Pygorhynchus Spratti*, and species of *Brissus*,

[1] 'Proceed. Geol. Soc.,' vol. iv. p. 225, and 'Quart. Journ.' vol. xxiii. p. 283.

Clypeaster, *Prenaster*, *Eupatagus*, and *Scutella*. The fine Urchin, *Conoclypus plagiosomus*, is very characteristic. A Miocene Sirenian (*Halitherium*) is not uncommon.

Western Asia and Egypt. There are no marine strata of Miocene age in Asia Minor, nor do any occur until the Isthmus of Suez, the coasts of Egypt, and the Soudan are reached. There limestones and sandstones containing a Falunian fauna are met with. Amongst the fossils are the teeth of *Carcharodon megalodon*, bones of Halitherium, with Echinoderms and various marine Mollusca. The silicified trees in the neighbourhood of Cairo are of this age[1].

Persia. There have recently been discovered in an indurated marl at Maragha, near Tabreez, the remains of a most interesting fauna, very similar to that of Pikermi. Dr. Pohlig[2] enumerates *Mastodon*, a *Rhinoceros* having teeth with low crowns like those of the *R. Schleiermacheri* (Boyd Dawkins), *Hipparion* (*H. gracile*), *Tragoceras* allied to the Pikermi species, *Palæoreas*, *Hyæna eximia* (?), *Helladotherium*, probably the same as at Pikermi, etc. To these Mr. Lydekker adds Giraffe (*Cameleopardis attica*), *Rhinoceros Blanfordi* (China and Siwaliks), *Hyopotamus*, *Anthracotherium*, etc.

India. Some marine beds of Miocene age, overlying Nummulitic limestones, are found in Pegu; and the Gáj beds of Sind, with *Arca Larkhanensis*, *Ostrea multicostata*, Desh., *Breynia carinata*, etc., together, possibly, with the upper part of the Nari beds, are of this age.

But the interest of the Indian Miocene deposits centres in the remarkable fauna of the Siwalik Hills, so perseveringly worked out by Dr. Hugh Falconer and Sir Proby Cautley, and so admirably illustrated by the former[3]. It includes several species of Quadrumana, an extraordinary number of Proboscidea, belonging to Mastodon and Elephas; several extinct species of Rhinoceros and Acerotherium; Chalicotherium; two new sub-genera of Hippopotamus; several species of Sus and Hippohyus, and of Equus and Hipparion; the Sivatherium, together with species of Camel, Giraffe, Deer, Antelope, and new types of Bovidæ; Carnivora belonging to the new genera, Hyænarctos and Enhydriodon, and to Drepanodon, Felis, Hyæna, Canis, Gulo, Lutra, etc. Among the Birds are species of Ostrich, Crane, etc.; among the Reptiles, Monitors and Crocodiles, and the enormous Tortoise, *Colossochelys atlas*, with species of Emys and Trionyx; and among Fishes, Cyprinidæ and Siluridæ. They are all of extinct species, with relations to European, African, and Asiatic types. Mr. Lydekker has since made considerable additions to this list, bringing up the number of species to ninety-three, comprised in forty-eight genera.

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[1] See L. Lartet's 'Géologie de la Palestine,' chap. viii.

[2] 'Quart. Journ. Geol. Soc.,' vol. xlii. p. 173.

[3] Hugh Falconer, 'Palæontological Memoirs: Fauna Antiqua Sivalensis,' edited by Charles Murchison, M.D., F.R.S.

Amongst the Siwalik fossils are some very remarkable forms. The *Sivatherium* was a gigantic ruminant, allied to the Antelopes, but with four horns. The head of the *Brahmatherium* was similarly furnished. The *Colossochelys atlas* far exceeded any living Tortoise in size. Falconer estimated that in full it had a length of 20 feet, and stood about seven feet high.

With these Vertebrates are associated a few land and fresh-water Mollusca, apparently of existing species, but their determination is uncertain. The strata consist of sandstones and conglomerates, with subordinate beds of clay, lying at a high angle, and forming a ridge of hills running parallel with the Himalayas.

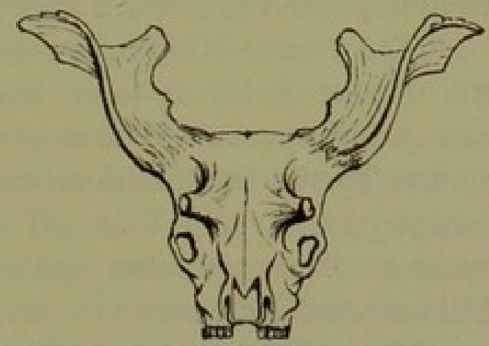

FIG. 206. *Skull of Sivatherium giganteum*, Falconer.

Falconer supposed these beds to be of Miocene age. The authors of the 'Manual of the Geology of India' and Mr. Lyddeker believe them to be Pliocene. There is certainly a very singular admixture of Miocene and Pliocene genera, with others which in Europe are Pleistocene and recent only. Hence arise three questions:—1. Whether the stratigraphical evidence is sufficiently complete. 2. Whether the Pleistocene and recent genera may not have been later in appearing in Europe than in India. 3. Whether the Miocene genera may have survived to a later period in India than in Europe.

The district is very inaccessible, and a large proportion of the remains have been obtained by native collectors, so that the precise geological position of all the bones is far from assured.

The testimony of land and fresh-water shells in questions of age is of comparatively little importance, seeing that in Europe those of the Pleistocene, and, in great part, those of the Pliocene periods, are living forms, and are associated with extinct Mammalia.

It is certain that the presence of species so nearly identical with the Buffalo of the Ganges Valley, of Sheep and Goat associated with a Crocodile and Tortoise inhabiting the same area, presents a great difficulty; but, with the uncertainty attached to the stratigraphy, this evidence does not outweigh, nor does it seem to be of equal force to, that afforded by the presence of Pseudælurus and Chalicotherium—genera occurring in the Upper Oligocene of Quercy—and of Amphicyon, Hipparion, Hyænarctos, Acerotherium, and Listriodon—genera which especially characterise, and in most instances do not range beyond, the Miocene in Western Europe.

If it be admitted that the Pikermi beds are Miocene and not Pliocene (as by some supposed), then the case becomes much stronger; for, in addition to many of the above, there are common to the two localities several peculiar genera, such as Camelopardis, Ictitherium, and Hystrix; and M. Gaudry has conclusively shown, both by superposition of the strata and the marked analogy of the Pikermi fauna with the well-known Upper-Miocene fauna of Sansan and Mont Léberon, that these three groups are in all probability on the same geological horizon.

Australia and New Zealand. There is little here to be added to the lists given in Tables IV and V. Strata of this age form the sea-cliffs near Portland in Victoria; yet, although so near New Zealand, Dr. Hector remarks that the species of Mollusca indicate that the strata were deposited in distinct zoological provinces.

The Lower-Miocene strata of New Zealand are very fossiliferous. Of the marine Mollusca there have been found about fifty-five existing and 110 extinct species. The most abundant genera are Dentalium, Pleurotoma, Conus, Turritella, Buccinum, and Cucullæa. In the Upper Miocene, on the contrary, it is said that out of 120 species, there are only twenty-five extinct. They include species of Ostrea, Murex, Fusus, Struthòlaria, Chione, and Pecten.

North America. The Miocene is represented in the Atlantic States by the *Yorktown series*, and in the Western States by the *White-River group* of Nebraska, and the *John-Day group* of Oregon. Strata of this age also occur in Colorado and California.

A remarkable feature connected with the series is the occurrence of Diatomaceous deposits at Richmond and Monterey. The former is thirty, and the latter fifty feet thick. They form light porous masses, as white as chalk, and are composed entirely of the siliceous remains of Diatoms and other microscopic organisms.

The distribution of the marine Mollusca on the Atlantic and Pacific borders shows even then a marked difference. The Miocene strata of the former contain species of Crepidula (*C. costata*, Say), Callista, Pecten, Cardium, Chama, and recent species of Ostrea (*O. Virginiana*), *Venus mercenaria*, Lam., Mactra (*M. lateralis*), Oliva (*O. littorata*, Lam.), Nassa (*N. limatula* and *N. trivittata*, Lam.), and Yoldia; whilst amongst the Californian genera and species are—Cerithidea, Neverita, Machæra, Lutricola, Yoldia (*Y. impressa*), Nassa (*N. fossata*), Lucina (*L. borealis*, Lin.), etc. One of the Oysters of the Californian and Oregon beds (*Ostrea Titan*) attained the great size of thirteen inches in length, eight inches in width, and six inches thick.

The Fishes in the Miocene beds on the Atlantic border show a striking analogy with those of the same age in Europe. Teeth of *Carcharodon megalodon* abound, and are of a size that indicates the animal itself to have been about 70 feet in length; *Galeocerdo latidens*, Ag., *Hemipristis serra*, Ag., *Oxyrhina hastalis*, Ag., also occur; and among the Mammalia are species of Lophiodon, Rhinoceros, Elotherium, Balæna, Delphinus, etc.

The most remarkable remains of this period, however, have been obtained from the great fresh-water lake-deposits of the Western States and Colorado[1]. The Brontotheridæ (Marsh) of the Miocene are not less remarkable than the Dinocerata of the Eocene, which they seem to have replaced. They equalled them in size and resembled them in several important features, though they are not of the same order. The head was armed with a pair of powerful horns, but the canine teeth were small and the molars large, the latter being of the type of those of Chalicotherium. The Diceratherium may be said to be a Rhinoceros with a pair of horns placed transversely. Mesohippus—a horse with three toes—is related to the Anchitherium of Von Meyer. The Oreodon of Leidy (*Eporeodon*, Marsh) was a singular animal, intermediate between the pig, the deer, and the camel. Besides these, there are found the Hyracodon, Aceratherium, and a monkey (*Laopithecus*) about the size of a Coati. Leidy has also described from these beds species of Hyæna, Wolf, Tiger, Tapir, Camel, Lama, Horse, Deer, Hare, Beaver, Squirrel, etc., thus presenting a case very analogous to that of the Siwalik Hills in this circumstance, that we here have several existing genera which in Europe did not make their appearance until in considerably later geological times.

Greenland. On the west coast of Greenland, between lat. 70° and 71° N., there are some beds with seams of lignite and a luxuriant flora, of which the genera and some species are, according to Professor Heer, identical with those of deposits in Central Europe. This flora, which he has described[2], consists of 169 species, of which 112 are Dicotyledonous plants, seventeen Monocotyledons, seventeen Coniferous, one Equisetum, thirteen Ferns, one Moss, and six Fungi. They are all of European Tertiary genera, and some even are of European Miocene species. According to Heer, there are eight such forms, including *Sequoia Couttsiæ*, Heer, *S. Langfordii*, Brong., *Corylus Mac-Quarii*, Forbes, *Sclerotherium cinnamoni*, Heer, *Glyptostrobus Europæus*, Heer, *Taxodium distichum miocænum*, Heer.

Heer was of opinion that this flora indicates a climate similar to that of the neighbourhood of Geneva at the present day, or 30° Fahr. higher than that of Greenland now.

In Grinnell Land, in lat. 81° 45′ N., another analogous deposit with plants and a bed of lignite, from 25 to 30 feet thick, was discovered by Captain Fielden during the Nares Expedition[3]. Twenty-six species were obtained from that locality, of which six are European Miocene species, four American (Alaska and Canada), eight agree with Greenland species, and seventeen with Spitzbergen. They indicate, like the Spitzbergen flora, a

[1] See papers and memoirs by Marsh, Cope, Leidy, and others.
[2] 'Nachträge zur Miocänen Flora Grönlands,' etc.
[3] 'Quart. Journ. Geol. Soc.,' vol. xxxiv. p. 66.

cooler climate than that which prevailed in West Greenland. Coniferæ are the most abundant plants. A species of the peculiar genus Torellia (*T. rigida*) is very common. The Cypresses are represented by a Thuytes, and by an abundance of the *Taxodium distichum-miocænum* so characteristic of the Miocene of Europe. The living representative of this tree now exists only in the south of the United States and in Mexico. Firs and Spruces were also found, together with *Phragmites Œningensis*. Amongst the dicotyledons is a Poplar (*Populus arctica*, Heer), two Birches, one Elm, two Hazels, and one Water-lily (*Nymphæa arctica*, Heer).

Spitzbergen[1]. Miocene strata occur in several places between 76° and 79° N. lat.; from these ninety-five species of plants have been obtained, including Alder, Hazel, Poplar, Birch, Plane, Lime, Sequoia, and some other genera. There is, however, an absence of trees or shrubs with evergreen foliage. Heer considers that this flora indicates a temperature lower than that which prevailed in Greenland, and more like that prevailing at the same time in Grinnell-Land.

When we look to the fact that trees do not now grow beyond 66° to 70° North latitude,—that in Spitzbergen the existing flora consists only of lichens, grasses, and a few herbaceous plants,—and that in Greenland nothing more than these and a few stunted shrubs can live, one is struck with wonder at the changes of climate and conditions which must have taken place in those latitudes within a so recent geological time. And yet that those trees did so grow and flourish is proved by their flowers and fruit, and that they abounded in numbers and in time is shown by the thick accumulated mass of vegetable matter necessary to form beds of lignite of the large dimensions there found.

Mr. Starkie Gardner[2], however, considers that the plants of these Arctic localities show close relations with those of Mull and Antrim; and, as he is of opinion that in these latter there is no plant common to any European Miocene deposits, but, on the contrary, that they agree with continental forms of Eocene age, he has, for his part, no hesitation in referring the Greenland flora to the same older Eocene age. But if it is necessary to make great allowances for variation in the leaves on the same tree, still more caution must be required in dealing with the foliage of trees which may be affected by differences of climate and soil.

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[1] Heer, *Op. cit.*; and Nordenskiöld, 'Geol. Mag.' for June, 1876, p. 259.

[2] 'Proceed. Roy. Soc.,' No. 235, p. 1, 1884.

CHAPTER XXVI.

THE PLIOCENE SERIES.

THE ST. ERTH AND LENHAM BEDS: UNCERTAINTY OF THEIR AGE: POSSIBLY DIESTIAN. BOX-STONES OF SUFFOLK. DERIVED FOSSILS. THE WHITE (CORALLINE) CRAG: ITS SUBDIVISIONS. POLYZOA. ORGANIC REMAINS. DERIVED MAMMALIA. INSETTING OF COLD CONDITIONS. TRANSPORTED BLOCKS. RED CRAG. FORMED ROUND THE OLDER CRAG ISLETS. DERIVED MATERIALS AND FOSSILS. ORGANIC REMAINS. COPROLITE BED. NORWICH CRAG. NORTHERN AND FRESH-WATER CONDITIONS. ORGANIC REMAINS. CHILLESFORD BEDS. COLDER SEAS. TYPICAL SHELLS. VALUE AS A HORIZON. PROPORTION OF EXISTING SPECIES IN THE THREE CRAGS. PROPORTION OF NORTHERN AND SOUTHERN SPECIES. BURE VALLEY AND WEYBOURNE CRAG. SCOTLAND. FOREIGN EQUIVALENTS. BELGIUM: TWO DIVISIONS. HOLLAND: DEEP-SEATED CRAG-BEDS: WELL-SECTIONS. GREAT THICKNESS OF THE CRAGS. FRANCE: THE BOSQ D'AUBIGNY: THE SUB-APPENNINE BEDS OF THE MEDITERRANEAN COAST. FRESH-WATER PLIOCENES OF AUVERGNE AND CANTAL. ST. PREST. PLANTS OF THE CINERITE BEDS. ITALY: MONTE MARIO: VAL D'ARNO. SICILY. INDIA AND AUSTRALASIA. NORTH AMERICA.

St. Erth and Lenham. Besides the typical crags of Norfolk and Suffolk, there are two small local deposits which I place with the Pliocene provisionally, namely (1) the sands and clays of St. Erth, and (2) the Lenham sands. In neither case can the age be determined by superposition; nor is the palæontological evidence at present sufficient to determine their exact age, although there can now be no doubt of their proximate position.

The St. Erth beds occupy a small depression in the slate and granite district north of Penzance, at an elevation of 98 feet above the sea-level. The shells, which are found in the upper clay-bed, are mostly in an excellent state of preservation. Species of Nassa, Turritella, Cerithium, and Natica are the predominant shells; and they seem to present a singular admixture of Miocene and Pliocene forms, possessing on the whole, according to Mr. S. V. Wood and Dr. Gwyn Jeffreys, an essentially Southern character[1]. Out of forty-five species, Dr. Jeffreys could only recognise ten or twelve as living forms, while twenty-two were unknown to him either as Tertiary or recent.

[1] 'Quart. Journ. Geol. Soc.,' vol. xli. p 65.

Mr. P. F. Kendall's and Mr. Robert Bell's more recent researches[1] have increased the number of known species to seventy-seven, of which they consider that twenty-four agree with species in the Miocene[2] beds of the Continent, forty-four with those of the Crags of Norfolk and Suffolk, while fifty-six are recent forms. But they still leave about twenty not known either in a fossil or a recent state. They are, however, of opinion that the St. Erth deposit was probably formed early in the Red-Crag period; and account for the absence of the common boreal shells of the Suffolk Crag by supposing that the two areas were then divided by a tract of land; while the number of Mediterranean shells leads them to conclude that a communication existed with that sea through the South of France.

On the other hand, it is to be observed that, even excluding the twenty undetermined species, the proportion of extinct to recent species is about twenty-six per cent., which is considerably higher than that of the Crag; while, if the twenty species, which on Dr. Jeffreys' authority cannot be referred to recent species, are to be considered as extinct, the proportion of extinct forms will be still higher, and the percentage will approach nearer to that of some of the Faluns of Miocene age. Amongst the shells of St. Erth are—

Nassa granulata, *Sby.*	Cerithium reticulatum, *Da Costa, var.*
,, reticostata, *Bell.*	Pecten opercularis, *Linn.*
Turritella triplicata, *Brocchi.*	Nucula sulcata, *Bronn.*
Natica multiplicata, *Lam.*	Cardium papillosum, *Poli.*

The large size which some of the shells attain is worthy of note.

It is possible that the more extensive, but unfossiliferous, sands and clays of St. Agnes, on the north coast of Cornwall, may be of the age of the St. Erth beds.

The Lenham sands[3] have a far wider range than the deposit just described, but the only spot where fossils have been found is on the summit of the Chalk Downs above Lenham in Kent. They occur, however, only as casts and impressions in blocks of iron-sandstone intercalated in thin beds of light-coloured sands and clays. They have been there preserved by the chance circumstance of their having been let down into a cavity (sand-pipe) in the Chalk, and having thus escaped the denudation which has swept away the greater part of a deposit that originally had a wide extension over the Chalk-hills of North Kent and probably of Surrey. Now only a few patches of sand and a coarse ferruginous sandstone (without fossils except at Lenham) remain here and there on the top of the Chalk-hills to

[1] 'Quart. Journ. Geol. Soc.,' vol. xlii. p. 201.

[2] I do not give the species they attribute to the Continental Pliocene, owing to the uncertainty of the horizon of some of the beds quoted.

[3] See 'Quart. Journ. Geol. Soc.,' vol. xiii. p. 322. The Lenham beds were discovered by Prof. Rupert Jones.

attest to the former presence of this deposit. Notwithstanding the condition of the Lenham shells, it has been possible to make out a sufficient number of species to show what may probably have been the relation of the beds. About twenty species are determined with more or less certainty, the more common species being,—together with species of Astarte, Isocardia, Cardium, Ringicula,—

Terebratula grandis, *Blum.* Fig. 207.	Scalaria subulata, *Sby.*
Nucula depressa, *Nyst.*	Nassa prismatica, *Brocchi.*
Pectunculus glycimeris, *Linn.*	Crassatella concentrica, *Duj.*

These are sufficient to disprove the connection of this deposit with the Lower-Tertiary Strata, to which they have been referred[1]; while its high level, its lithological character,—its position (on the Chalk before the excavation of the Wealden area),—and the presence of certain species which cannot be identified with Crag-forms, tend to show that it may be somewhat older than the Crag-beds of Suffolk.

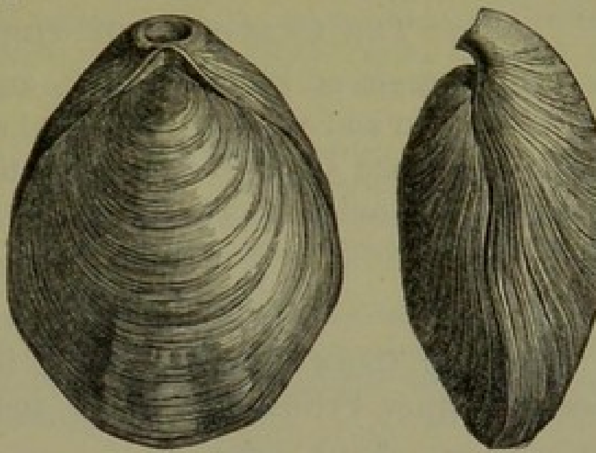

FIG. 207. *Terebratula grandis*, Blum. (From a White Crag specimen, reduced ⅓rd.)

That there may be strata of this character older than the Crags of Suffolk, and adjacent to that area, is indicated by the fact that in the Coprolite-bed at the base of the Red Crag at Bawdsey and Sutton, near Woodbridge, there are found, together with other extraneous fossils, round iron-sandstone concretions of the size of an orange (Box-stones), derived from some older bed, and containing commonly the cast or impression of a shell. Amongst them Professor Ray Lankester recognised the following species[2]:—

*Pyrula reticulata, *Lam.*	Cardium decorditatum, *Wood.*
*Conus Dujardinii, *Desh.*	Pectunculus glycimeris, *Linn.*
Voluta Lamberti, *Sby.* Pl. XV, fig. 21.	*Isocardia lunulata, *Nyst.*

Those marked with an asterisk are common and characteristic shells of the Mio-pliocene (Mourlon) of Belgium.

In connection with these box-stones, Professor Lankester also found some Carcharodon and Ziphoid-teeth, together with the tooth of a Trilophodont Mastodon. The same Coprolite-beds contain teeth of *Tapirus priscus*, *Ursus Arvernensis*, *Hipparion*, *Trichecodon*, and *Squalodon* (*S. Antwerpiensis*), all of Miocene or Plio-miocene forms[3].

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[1] That they are not Eocene may now be considered as decisively settled by the recent researches of Mr. Clement Reid. See a note by Dr. Archibald Geikie, in 'Nature' for Aug. 12, 1886.

[2] 'Quart. Journ. Geol. Soc.,' vol. xxvi. p. 493.

[3] Amongst the derived Cetacea of the Crag, Mr. Lydekker ('Quart. Journ. Geol. Soc.' No. 169, February, 1887, p. 17) has also determined the following Belgian and French Miocene or Mio-pliocene species:—

Megaptera affinis, Van Ben.	*Hoplocetus crassidens*, Gerv.
Eucetus amblyodon, Du Bus.	*Physodon grandis*, Du Bus.

These derived fossils represent, therefore, an older arenaceous deposit, probably an equivalent of the sands of Lenham and of the Diestian beds of Belgium and Northern France, described in the last chapter.

The Lenham and Paddlesworth ironstones may, like the ferruginous Diestian beds of Belgium, have originally consisted of glauconiferous sands, which, by exposure to the action of the surface-waters, became oxidised and decomposed, the green silicate of iron being converted into a brown hydrated peroxide, which concreted round the shells (see Vol. I, p. 141), while the calcareous tests of the shells were subsequently removed by the percolation of the surface-waters.

THE CRAG-BEDS OF THE EASTERN COUNTIES[1].

The coasts of Essex, Suffolk, and Norfolk are fringed by a belt of light-coloured and ochreous sands and shingle, often very fossiliferous, rarely rising more than 50 to 60 feet above the sea-level, and nowhere extending more than 20 miles inland. They are divided into,—

1. The Chillesford Beds.
2. The Norwich and Red Crags.
3. The White ('Coralline' of Charlesworth) Crag.

White Crag[2]. This division is confined to a very limited area around Sutton, Felixstowe, Orford, and Aldborough, and a small outlier at

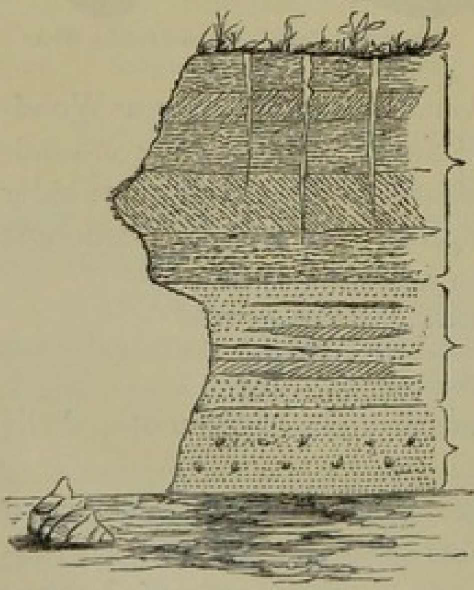

FIG. 208. Section of White Crag, Sutton, near Woodbridge.

Tattingstone, west of Ipswich. It forms two subdivisions. The lower consists of calcareous sands, some beds of which contain lines of Polyzoa in the position of growth, and shells in a fine state of preservation, the

[1] The author in 'Quart. Journ. Geol. Soc.,' vol. xxvii. See also Lyell, 'Proceed. Geol. Soc.,' vol. iii. pp. 126 and 437; Searles V. Wood, jun., 'Ann. Nat. Hist.,' March, 1864; and his several later papers, and those of Mr. F. W. Harmer in 'Quart. Journ. Geol. Soc.'

[2] First called by Mr. Charlesworth 'Coralline Crag,' on the supposition that the numerous Polyzoa were Corallines. The term 'White Crag' which has been proposed is, I think, preferable.

bivalves often double; while at the base there is a thin bed of phosphatic nodules with Mammalian remains, Shells, Sharks' teeth, ear-bones of Whales, etc. The upper subdivision consists of a base of comminuted Shells, and more especially of Polyzoa (with perfect specimens of both), and exhibits constant oblique lamination. The two divisions together are at their maximum from about 60 to 80 feet thick.

The section at p. 418, which was taken in an old quarry on the top of the hill at Sutton Farm, gives the general structure of the White Crag.

Organic Remains are extremely abundant, and are easily collected in the many sand- and shell-pits of the district.

Of the *Foraminifera*[1] there are 105 species—with some notable varieties, remarkable for their size and abundance—belonging to the genera *Miliola, Polystomella, Rotalia, Lagena, Nodosaria.*

Corals. Corals are scarce, and are confined to three species of *Flabellum, Sphenotrocus,* and *Cryptangia,* which are all extinct.

Echinodermata. Sixteen species have been found, of which three are recent.

Crustacea[2]. A very few well-preserved specimens of decapod Crustaceans are found, including *Gonoplax angulata, Cancer pagurus,* Linn., but Entomostraca are common, and amongst the most characteristic are *Cythere trigonula, C. Woodiana, C. trachypora, Cytheridea pinguis,* and *Bairdia subdeltoidea*—altogether eighteen or more species.

Polyzoa[3]. Of these there are no fewer than ninety-five species, of which thirty are living and sixty-five extinct. Amongst the extinct forms are the curious globose genera, *Alveolaria* and *Fascicularia* (Fig. 210, *d*); these are peculiar to the White Crag. Amongst other forms are species of the genera *Idmonea* and *Retepora,* and the delicate *Salicornaria.*

The *Mollusca*[4] and *Brachiopods* (five, of which the *Terebratula grandis* is very common) together amounted to 317 species, of which 265 are living, and fifty-two are extinct. Amongst the characteristic species are—

Terebratula grandis, *Blum.* Fig. 207.
Astarte Omalii, *Lajonk.*
Astarte Burtini, *Lajonk.* Pl. XIV, fig. 14.
Cardita senilis, *Lam.*
Cyprina Islandica, *Linn.*
Isocardia cor, *Lam.*
Mya truncata, *Linn.* Pl. XVI, fig. 2.
Panopæa Faujasii, *Sby.* Pl. XIV. fig. 17.
Pecten opercularis, *Linn.*
Modiola sericea, *Bronn.*
Tellina crassa, *Penn.*
Natica multiplicata, *Wood.*
Buccinum Dalei, *Sby.*
Bulla lignaria, *Linn.*
Pyrula acclinis, *Wood.* Pl. XIV, fig. 24.
Pleurotoma porrecta, *Wood.*
Pyramidella læviuscula, *Wood.*
Eulima subulata, *Mont.*
Nassa semistriata, *Brocc.*
Scalaria frondicula, *Wood.* Pl. XIV, fig. 22.
Trochus millegranus, *Phill.*
Turritella incrassata, *Sby.*

According to the late Dr. J. Gwyn Jeffreys, the distribution of the 265 living species is as under:—

Species living in Arctic and Scandinavian Seas	169
" " British Seas	185
" " the Mediterranean	200
" " Mid Atlantic	99
" " Deep Atlantic	92

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1 'The Crag Foraminifera,' by T. Rupert Jones, W. K. Parker, and H. B. Brady, 1865–6.
2 'The Ostracoda of the Crag,' in 'Tertiary Entomostraca,' 'Palæont. Soc. Monogr.' 1856.
3 'The Fossil Polyzoa of the Crag,' by G. Busk, F.R.S., 'Palæont. Soc. Monogr.,' 1859.
4 'The Crag Mollusca,' by S. V. Wood, 'Palæont. Soc. Monographs' from 1847 to 1882.

Remains of *Fishes* are scarce, owing apparently to the fact that so many of them weer of cartilaginous kinds, of which only the teeth and dermal spines are preserved. With these also are found a few small vertebræ of Teleostean fishes, and Otolites probably of Cod and Whiting.

Cetacea. The skull-bones of the Belemno-ziphius, together with the ear-bones of Whales, etc., are common in the Basement-bed, but these, like the abundant *Carcharodon* teeth, have been mostly derived from older beds. These fossils are highly mineralised; and, together with the flat Cetacean bones, have been drilled superficially by some boring animal. A species of Whale was, however, judging from the state of the bones, certainly cotemporaneous with the deposit itself.

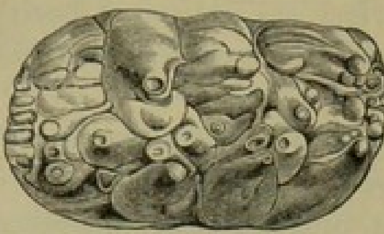


FIG. 209. *Crown of tooth of Mastodon (Tetralophodon) Arvernensis,* Croizet and Jobert.

Mammalian Remains. The White Crag may be as rich in Mammalian remains as the Red and Norwich Crags, only that it is very rarely that the bone-bed is exposed. A number of teeth of *Mastodon Arvernensis, Rhinoceros Schleiermacheri,* and *Cervus,* with skulls of Ziphius, were found by Mr. W. Colchester in the one small pit opened some years ago near Sutton.

The Fauna of this period is of peculiar interest. It marks the insetting of the cold conditions, which gradually culminated in the Glacial Period. Although a large number of the Mollusca are of Mediterranean and Atlantic species, still the presence of 135 Scandinavian and thirty-four Arctic species is a noticeable fact. The Foraminifera of the Crag are in general best represented by dredgings in the Atlantic south of the Scilly Islands, nevertheless there are amongst them thirty-seven species now living in the North Atlantic and Arctic Seas. It is clear, therefore, that at that time colder waters or floating ice must have commenced to influence the denizens of these seas; and this is confirmed by the fact that in the basement-bed of the White Crag, there are found fragments of Oolitic rocks, which apparently came from Central England, together with one large block of red porphyry from a yet more distant land, and such as, from its size and position, could only be due to ice-transport.

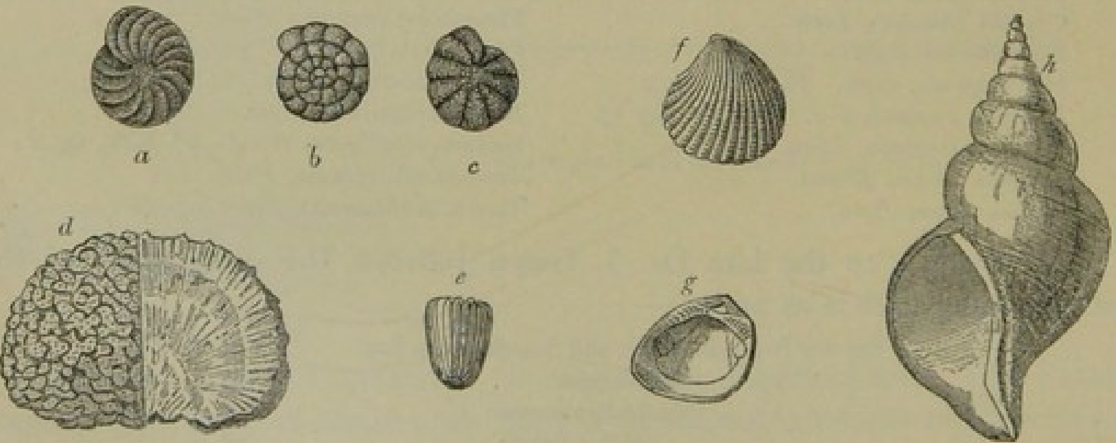
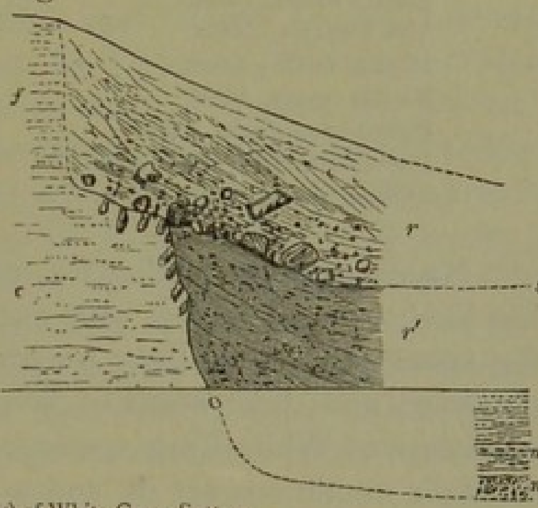


FIG. 210. Crag Fossils (see also Pls. XIV and XV).
a. Polystomella crispa (Linn.) × 6. *b, c. Rotalia Beccarii* (Linn.) × 6. *d. Fascicularia aurantium,* M. Edw. *e. Sphenotrochus intermedius,* M. Edw. *f. Cardita scalaris,* Sby. *g. Limopsis aurita,* Broc. *h. Fusus contrarius,* Sby, ½.

Red Crag. The White-Crag sea seems to have been of moderate depth—50 to 70 fathoms, and gradually to have become shallower; for the upper Polyzoan beds, with their large proportion of comminuted fossils, and prevailing false-bedding, indicate the action of the strong tides and currents of a shallow sea. Finally, the White Crag sea-bed was raised above the sea-level, and then worn down into small islets or reefs, round which accumulated the beds of the Red Crag. A section cut through an old cliff of one of these islets in a pit at Sutton is interesting on account of its showing how these causes operated.

From the circumstance that an old cliff of White Crag has here been perforated by *Pholades*, and the beach of the Red Crag strewed with flint débris and fragments derived from the older Crag, it is evident that we have a former shore-line, extending, like the Red Crag itself, all round this small islet. Great blocks of compact White Crag, which then rose as a cliff above the Red-Crag sea, toppled over into the sea, depressing the soft sandy beds on which they fell, and where they were eventually covered up by succeeding beds of Red Crag.



f. Partially consolidated White Crag.

s. Second shore-line with blocks of White Crag (f), Coprolites, &c., in Upper Red Crag (r).

c. Sandy White Crag, perforated by Pholas-borings.

r′. Lower bed of Red Crag, with layer of Mytili (m) and Coprolites (n) at its base (First shore-line).

FIG. 211. Section of an old cliff (*o*) of White Crag, Sutton.

Together with these local blocks, there are large massive chalk flints, unworn and covered with *Balani*, evidently transported from a distant chalk-shore. The basement- or Coprolite-bed (*n*) of the Red Crag also contains large quartzite pebbles, fragments of Lower-Greensand chert, and of red Granite. All this indicates transport from a distance; and, as the large flints are perfectly angular and unworn, they were doubtlessly carried there by shore-ice, and left on the strand where the ice-floes grounded.

There is another such islet of White Crag at Tattingstone. In the intermediate area the Crag has been removed, and its débris spread over the adjacent area, under the influence of the shifting currents which circulated amidst the islets and along the adjacent Tertiary and Chalk coast. Consequently, a large proportion of the Red Crag consists of re-formed comminuted materials and débris of the White Crag, though at the same time there are many entire, and even double, shells left in the more sheltered places, or where drifted out into deeper and less disturbed water.

It follows from these conditions, that a large number of White-Crag species have been introduced into the Red Crag; and, as they have been mostly stained alike of the same red ferruginous tint which characterises the Red-Crag shells, it is often difficult to determine the species proper to the Red Crag and those which have been derived from the White Crag.

Organic Remains. The Mollusca of the Red Crag consist of 234 species, of which 216 are living and eighteen extinct. It is estimated that forty-six species are derived from the White Crag, leaving 188 as the number of Red-Crag species; but 140 of these are common also to the older Crag, only forty-eight being new forms.

The more abundant species of the Red Crag are—

Astarte sulcata, *Da Costa.*
Cardium edule, *Linn.*
,, Groenlandicum, *Chemn.*
Cyprina Islandica, *Linn.*
Leda myalis, *Couth.*
Lucina borealis, *Linn.*
Mactra solida, *Linn.*
Mya arenaria, *Linn.*
Mytilus edulis, *Linn.*
Nucula tenuis, *Mont.*
Pecten opercularis, *Linn.*
Pectunculus glycymeris, *Linn.*
Tellina crassa, *Penn.*
Buccinum undatum, *Linn.*
Calyptræa Chinensis, *Linn.*
Cerithium tricinctum, *Broc.* Pl. XIV, fig. 19.
Cypræa Europæa, *Mont.*
Emarginula fissura, *Linn.*
Littorina littorea, *Linn.*
Nassa granulata, *Sby.*
Natica Groenlandica, *Beck.*
Purpura lapillus, *Linn.*
Ringicula ventricosa, *Sby.* Pl. XV, fig. 20.
Turritella incrassata, *Sby.*
Trophon antiquum, *Müll.* (Fusus contrarius, *Sby.*) Fig. 210, *b.*
Voluta Lamberti, *Sby.* Pl. XV, fig. 21.

Necessarily, the further we recede from these White-Crag centres, the less likely are we to meet with extraneous species, and the more so to find the fauna of the Red-Crag proper. It is in the Crag beds of Walton-on-the-Naze, and those north of Woodbridge, that we meet with beds freer from derived White-Crag species; whilst as we proceed into Norfolk, more fluviatile conditions set in, and a still greater number of peculiar species make their appearance, accompanied by an increase in the proportion of northern species.

The *Mammalian remains* in the Red Crag seem to be more numerous than in the White-Crag, but this may be accounted for from the fact that the Coprolite-beds at the base of the Red Crag are very extensively worked at Sutton, Waldringfield, and elsewhere; whereas the one small pit at Sutton, temporarily opened, furnished all the Mammalian specimens known from the White Crag. It is in fact probable that most of the Mammalian remains found in the Red Crag are *derived* from the White Crag and older beds. Among the species in the Red Crag are—

Mastodon Arvernensis, *Croizet and Jobert.*
Rhinoceros Schleiermacheri, *Kaup.*
Tapirus priscus, *Kaup.*
Ursus Arvernensis, *Croizet and Jobert.*
Equus caballus fossilis, *Rüt.*
Cervus dicranoceros, *Kaup.*
Felis pardoides, *Ow.*
Hyæna antiqua, *Lank.*

together with species of Elephas, Castor, etc. The Cetacea are mostly the same as those before enumerated from the White Crag. The ear-bones of Whales and the large teeth of the *Carcharodon* are especially abundant.

Coprolite-Bed. The greater part of the Mammalian remains, together with a profusion of shells (*Buccinum*, *Purpura*, etc., with single valves of *Pectunculus*, *Tellina*, *Pecten*, etc.), occur in the so-called Coprolite-bed lying at the base of the Red Crag. This bed, which is from one to four feet thick, is composed, in greater part, of rolled and worn phosphatic nodules. Most of these were originally argillo-calcareous concretions, derived from the London Clay, and subsequently altered in presence of abundant organic matter (*ante*, p. 301). Many of them contain the Crabs and Lobsters of the London Clay. A few have been formed by the excretion of Sharks and other large fishes. These concretions have been largely worked as a fossil manure, and the pits afford numerous excellent sections of the lower beds of the Red Crag.

Norwich Crag (**Mammaliferous Crag**, Charlesworth). As the Red Crag trends northward, the lower beds thin out, and new species of Mollusca gradually appear, especially in the upper subdivision, such, for example, as the *Conovulus pyramidalis*, Sby., and *Astarte borealis*, Chemn.; and the proportion of littoral shells, such as Littorina, Mactra, and Mya, largely increases, while the presence of Limnæa, Paludina, etc. indicates more fresh-water conditions. At the same time a larger number of northern species appear, and the deposit gradually takes the fluvio-marine and more northern type characteristic of the Norwich Crag. There is, however, a break in North Suffolk between the area of the Red Crag and that of the Norwich Crag proper. The beds in this latter district are not so largely developed,—are of a lighter colour, and exhibit more littoral and fresh-water conditions. They seem to correspond in age with the upper subdivision of the Red Crag, which in the Red-Crag district contains but few fossils, and immediately underlies the Chillesford Beds.

The localities where the Norwich Crag is best exhibited are at the pits of Thorpe and Bramerton near Norwich, where they overlie the Chalk. They vary in thickness from 5 to 30 feet, and consist of fossiliferous light-coloured sands, with large flints and flint pebbles at the base.

Organic Remains. Amongst the characteristic and common shells of this deposit are—

Astarte compressa, *Mont.*
Cardium edule, *Linn.*
Cyprina Islandica, *Linn.*
Mactra solida, *Linn.*
Mya arenaria, *Linn.*
Mytilus edulis, *Linn.*
Nucula Cobboldii, *Sby.* Pl. XIV, fig. 13.
Tellina calcarea, *Chem.* Pl. XIV, fig. 6.
„ prætenuis, *Woodw.*
Pecten opercularis, *Linn.*
Corbula striata, *Lam.*
Lucina borealis, *Linn.*
Cyrena fluminalis, *Müll.* Pl. XVI, fig. 15.
Cyclas cornea, *Linn.* Pl. XVI, fig. 15.
Buccinum undatum, *Linn.*
Cerithium tricinctum, *Brocc.* Pl. XIV, fig. 19.
Littorina littorea, *Linn.*
„ rudis, *Maton.*
Natica catena, *Da Costa.*
„ hemiclausa, *Brod.* Pl. XIV, fig. 18.
Purpura lapillus, *Linn.*
Trophon antiquum, *Müll.* Fig. 210, *h*.
Turritella communis, *Risso.* Fig. 215, *a*.
Conovulus pyramidalis, *Sby.*
Helix hispida, *Müll.*
Paludestrina subumbilicata, *Mont.*
Limnæa palustris, *Linn.* Pl. XVI, fig. 23.
Paludina lenta, *Sby.*

Including the land and fresh-water species, the total of the Molluscan fauna of the Norwich Crag amounts to 163 species. With these are found many Mammalian remains, which are here of contemporary age, the more common being—

Mastodon Arvernensis, *Croizet and Jobert.*	Cervus Falconeri, *Dawkins.*
Elephas meridionalis, *Nesti.*	Hyæna antiqua, *Lank.*
Felis pardoides, *Owen.*	Trogontherium Cuvieri, *Fisch.*

With these are associated species of Ursus, Equus, Bos, and Arvicola; numerous teeth of Shark (*Lamna*); dermal spines of the *Platax Woodwardii* and *Raia antiqua*; Vertebræ and Otolites of bony Fishes; fragments of Balani, Crabs, and Echini. The fossils are of very local occurrence; at the large pit at Bishopfordbridge, Norwich, which is only two miles distant from the rich pit of Thorpe, scarcely any remains of shells are to be found[1].

Chillesford Clay and Sand. The Red Crag passes upwards into light-coloured sands and laminated clays, ten to twenty feet thick, in which shells occur commonly in the position in which they lived, and of more definite northern types than in the underlying Red Crag. No line of demarcation can be drawn between the upper sands of the Red Crag and the lower Chillesford bed or *Sands*, both of which are probably synchronous with the Norwich Crag. These Chillesford beds clearly indicate a gradual deepening of the sea, and colder and quieter waters in certain areas.

The typical shells at Chillesford are—

Mya truncata, *Linn.* Pl. XIV, fig. 2.	Lucina borealis, *Linn.*
Leda myalis, *Couth.*	Cyprina Islandica, *Linn.*
Cardium Groenlandicum, *Chemn.*	Turritella communis, *Risso.* Fig. 215, *a.*
Panopæa Norvegica, *Sby.*	Buccinum undatum, *Linn.*

The Chillesford Clay-bed, with its northern types of burrowing bivalves, ranges northward, and forms a very definite horizon with reference to both the Red Crag and the Norwich Crag, which it overlies.

We have thus, as pointed out by Lyell, in the several divisions of the Crag, a very interesting example of the gradual increase of the number of living species in the ascending strata, and at the same time an excellent illustration of the increasingly low temperature which inaugurated the Glacial Period. This is shown in the following Tables, in which the land and fresh-water shells, which do not afford equal terms of comparison, and the extraneous and doubtful species, are excluded.

	Total Species.	Living Species.	Extinct Species.	Proportion of Extinct Species.
Norwich Crag ...	139	130	9	6·5 per cent.
Red Crag	234	216	18	7·7 "
White Crag ...	316	264	52	16·0 "

[1] The reader should consult Mr. H. B. Woodward's 'Geology of the Country around Norwich,' 'Mem. Geol. Survey,' 1881.

In the same way, the relative proportion of northern and southern species of the three Crags is as under:—

	Total Living Species.	Species now restricted to Northern Seas.	Southern Seas.
Norwich Crag	130	19	11
Red Crag	216	23	32
White Crag	264	14	65

It is instructive also to notice the gradual insetting of northern species in the Red and Norwich Crags in proceeding from the south of Suffolk to the north of Norfolk. Thus, at Bulchamp the *Astarte borealis* first appears; in the neighbourhood of Norwich the *Rhynchonella psittacea* and the *Littorina rudis*; and then *Tellina Balthica*.

Bure Valley and Weybourne Crags. Some uncertainty still exists with reference to the exact synchronism of the Crags of the north of Norfolk, owing to the thinning out of some strata and the changes of condition. I see, however, no occasion (especially since Mr. Clement Reid has given the more complete list of the Weybourne shells[1]) to consider the Weybourne and Bure-Valley Crags as anything more than a slightly more northern type of the Norwich Crag, with *Tellina Balthica* and *Astarte borealis* in addition to the other species. It may be that it is the upper part of the Norwich Crag or the Chillesford Sands which are there represented; and it is hardly a sufficient reason to place these beds on a higher horizon, inasmuch as the localisation of individual species of shells is very irregular. As just mentioned, northern species are not only in greater proportion proceeding northward, but new species from time to time appear, both in the Red and Norwich Crag[2].

Scotland. A few years ago Mr. Jamieson[3] discovered some stratified sands and gravel underlying the Boulder-clay, on the coast about midway between Aberdeen and Peterhead, in which he found much-worn fragments of a number of shells, which he considered to show affinities with the Crag rather than with the Glacial series; so that it is possible that the Red-Crag Sea extended into that neighbourhood. The following are some of the species which he was enabled to determine:—

Cyprina rustica, *Sby.*
,, Islandica, *Linn.*
Pectunculus glycimeris, *Linn.*
Fusus contrarius, *Sby.*
Nassa reticosa, *Sby.*

Foreign Equivalents. Owing to the further retreat of the European seas in Pliocene times, the strata of that age are in general confined, as in Britain, to within a comparatively short distance of the coast-line.

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1 'Mem. Geol. Survey': 'Geology of the Country round Cromer,' p. 18.
2 See Messrs. Woodward and Reid's papers before quoted.
3 'Quart. Journ. Geol. Soc.,' vol. xvi. p. 371.

Belgium. In the neighbourhood of Antwerp a series of sand- and shell-beds overlies the Rupelian strata. The numerous fine sections exposed in the excavations made during the construction of the surrounding forts and the new docks have yielded rich stores of organic remains. The remains of Cetaceans especially were so abundant that Professor Van Beneden was led to remark that these strata form the greatest ossuary the world ever saw. As the result of united observations, the Belgian geologists have classified these beds in the following order[1] :—

Sables à *Trophon antiquum* Sables à *Isocardia cor*, with Couche à Hétérocètes and Sables à *Bryozoaires*	Scaldisian System.	Pliocene.
Sables à *Pectunculus pilosus* Sables à *Panopæa Menardi*	Diestian or Anversian (Bolderbergian).	Mio-pliocene.

Some Belgian geologists consider that all these beds, which here follow in conformable order, and which together are not 100 feet thick, form a consecutive series of Pliocene age; whereas others, on palæontological grounds, place the lower divisions in the Upper Miocene, or as passage-beds under the term of Mio-pliocene. The Diestian deposits of the border districts were raised apparently before the deposition of the Scaldisian, so that this circumstance, in conjunction with the palæontological evidence, is a reason for placing them, as we have done, in the last chapter.

The Scaldisian series, or the 'Isocardia-cor Sands,' consists of (1) a basement-bed of pebbly sands (Sables à Hétérocètes), in which lie more especially the prodigious quantity of Cetacean bones just alluded to; (2) an irregular local bed rich in Polyzoa, of which there are above 100 species, most of them common to our White Crag, together with *Terebratula grandis* and *Lingula Dumontieri*, etc.; and (3) shelly sands of a dark greenish-grey colour, passing up into light-brown. According to Professor Van Beneden, the Cetacea belong to species of Balæna, Balænula, Balænotus, Megoptera, and Balænoptera[2]; there are also some species of Seal. These beds likewise contain an abundant Molluscan and Entomostracan fauna.

Amongst other characteristic shells are,—

Cassidaria bicatenata, *Sby.*	Lucina borealis, *Linn.*
Ringicula buccinea, *Brocc.*	Astarte Omalii, *Laj.*
Natica cirriformis, *Sby.*	Cyprina Islandica, *Sby.*
Turritella incrassata, *Sby.*	,, rustica, *Sby.*
Scalaria frondicula, *S. Wood.* Pl. XIV, fig. 22.	Cardita senilis, *Lam.*

The upper division of the Scaldisian, or the 'Trophon-antiquum

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[1] See the various papers by MM. Nyst, Dewael, Dewalque, Cogels, Van Ertborn, Gosselet, Van den Broeck, Rutot, Mourlon, etc. M. Van den Broeck divides the whole of the above series into Lower, Middle, and Upper Antwerp Sands ('Dépôts Pliocènes des Environs d'Anvers,' 1876–1878).

[2] A nearly entire skeleton of *Balænoptera musculoides* was found. It is now mounted in the Brussels Museum.

Sands,' consists of beds of light-coloured [1] shelly sands, corresponding with our Red Crag. The following are amongst the common shells :—

Trophon gracile, *Da Costa*.
Nassa labiosa, *Sby*.
Pleurotoma costata, *Da Costa*.
Purpura lapillus, *Linn*.
Astarte Basteroti, *Laj*.
Pecten opercularis, *Linn*.
Corbulomya complanata, *Sby*. Pl. XIV, fig. 16.
Tellina Benedeni, *Nyst*.

The *Voluta Lamberti*, so common in both the Crags of England, seems confined to this upper zone in Belgium, and the *Terebratula grandis*, so abundant in both the Suffolk zones, is confined to the lower zone in Belgium, and is there rare.

Holland. While in Belgium and England we have only the littoral and shallow-water deposits of the Crags, beds of the same series, but deposited in deeper waters and much thicker, underlie the alluvial beds of Holland. This has been proved by three deep borings at Goes, Gorhum, and Utrecht [2].

The following table gives the thickness of the several groups passed through, and the total depths reached. The distance between Antwerp and Utrecht is about 70 miles in a straight line.

	Alluvial beds.	Delta beds.	'Trophon antiquum sands.'	'Isocardia Cor sands.'	Total depth.
	feet.	*feet.*	*feet.*	*feet.*	*feet.*
Goes	26	118	85	122	735 *a*
Gorhum	40	355	203 +	?	598 *b*
Utrecht	16	512	270	410 +	1208 *c*

a. The last 384 feet were in Rupelian strata. *b*. Left off in the Scaldisian. *c*. Left off in the Diestian (Mio-pliocene).

Notwithstanding the narrow diameter of the bore-hole, a considerable number of fossils (133 species) were obtained, many of them in a good state of preservation. Amongst these were specimens of *Terebratula grandis*, *Astarte Omalii*, *Cyprina rustica*, *Cardita senilis*, etc., referred by the author to the zone of the White Coralline Crag; and *Nucula Cobboldii*, *Tellina obliqua*, *Trophon antiquum*, etc., referred to the zone of the Red Crag.

The strata at these depths were found to consist of yellow and grey sands, often micaceous and glauconiferous, and of some beds of compact clay. It would thus appear that at the point (Goes) nearest to Antwerp, the Red and White Crags have attained a joint thickness of 207 feet; that at the

[1] These beds used to be known as the 'Crag jaune,' and the Isocardia-cor beds as the 'Crag gris'; but the colour is merely the effect of decomposition. The beds are grey when they pass under strata which protect them from the action of the surface-waters.

[2] Dr. J. Lorié, 'Contributions à la Géologie des Pays Bas'; 'Archives Teyler,' 2[e] sér., vol. ii. 1885. Dr. Lorié makes Diestian = White Crag, and Scaldisian = Red Crag. It is uncertain whether the Mio-pliocene is represented in those sections. *Pectunculus pilosus* and *Panopæa Menardi* are not given in the list of fossils.

greater distance of Gorhum the Red Crag alone exceeds 203 feet; while at Utrecht the latter has attained a thickness of 270 feet, and the White Crag of even 410 feet, or together of more than 680 feet.

France. At this time the sea had retired from the greater part of France, as it had of England, and the configuration of the land was much as it is now. In the central districts, therefore, land and fresh-water deposits are alone met with. But at the Bosq d'Aubigny, a short distance from St. Lo, in Normandy, M. Hébert[1] found in a shallow roadside section (which I visited a few years later) some twenty-two species of shells, of which the *Nassa prismatica* is by far the most abundant. Besides this there were *Corbula striata*, Walk. non Sby., *Astarte mutabilis*, *Natica multipunctata*, *Nassa propinqua*, etc. This bed appears to be of the age of the Red Crag.

It is doubtful whether any of the Faluns or shell-beds of Brittany can be referred to the Crag Period except possibly the 'Redon Clay' with *Nassa prismatica*, *N. mutabilis*, *Ostrea edulis*, and *Terebratula grandis*. A clay with similar shells has also been found near Sévérac (Loire-Inférieure)[2].

In the Bordeaux district, the sands of Dax with *Nassa prismatica*, *Cancellaria subancellata*, etc., and the unfossiliferous sands of the Landes, have been referred to Pliocene times.

On the coast of the Mediterranean, Sub-apennine (Pliocene) beds are met with in the Departments of the Aude and Hérault; but are more largely developed on the coast at Cannes, Nice, and Mentone. They there consist of lower grey clays, of which the characteristic fossils are *Ostrea cochlear*, *Pecten cristatus**, *Arca Diluvii**, *Corbula gibba**, *Pleurotoma turricula**, *Nassa semistriata**, etc., and of upper beds of yellow sands and clays with *Lucina orbicularis**, *Cardita intermedia**, *Nassa mutabilis*, *Natica multiplicata**, *Cerithium vulgatum**, etc., and numerous Foraminifera. The species marked with an asterisk are common to both zones; only they vary in their relative abundance. The lower division has 153 species, of which 53, or 35 per cent., are recent; and the upper with 136 species has 50, or 38 per cent. of recent species[3]. These strata are sometimes overlain by a pebbly and conglomeratic bed with some boulders. Though classed as Pliocene, these beds would seem on this evidence to be older than our Crags.

Further inland the Pliocene is represented at Hauterive, Lyons, and in the Auvergne, by occasional land and fresh-water beds with species of Helix, Clausilia, Limnæa, Paludina, etc., and a rich Mammalian fauna, in which are *Mastodon dissimilis*, *Rhinoceros leptorhinus*, *Cervus Pardinensis*, *C. mar-*

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[1] 'Bull. Soc. Géol. de France,' 2e sér., vol. vi. p. 559, 1849.

[2] G. Vasseur, *Op. cit.*, pp. 382, 384.

[3] Tournoüer, 'Bull. Soc. Géol. de France,' 3e sér., vol. v. p. 846; Depontaillier, *ibid.*, p. 77.

tialis (?), *Equus Stenonis*, *Elephas meridionalis* (?), *Machairodus megantherion*, etc.

At St. Prest[1], near Chartres, is a local deposit of sands and pebbles, resting on Chalk, and without any overlying strata. Limited as the deposit is, it nevertheless contains an important Mammalian fauna, referred by the French geologists to later Pliocene times. The species consist of *Elephas meridionalis*, *Rhinoceros leptorhinus*, *Hippopotamus major*, *Megaceros Carnutorum* (Laugel), *Conodontes Boisvilletti*, with species of Cervus, Equus, and Bos. No shells, nor other fossils than Mammalian, have been found there.

The vegetation, so rich during the Miocene period, now shows a marked change, and forms indicative of a gradual lowering of temperature replace the more tropical vegetation of the earlier Tertiary periods. The Falunian seas had retreated, leaving the land outlined much as it is at the present day, but with a number of fresh-water lakes in Central and Southern France, and in these the remains of the plants and remains of the land animals of the period have been preserved. The country then had its forests in the lowlands (Maximieux) and in the uplands (Ceyssac), with a vegetation in accordance with the differences of conditions. Amongst the trees which then flourished in the former, Saporta mentions *Quercus præcursor*, much resembling the existing *Q. ilex*, Laurels allied to those of the Canary-Islands, Limes, Maples, Walnuts, etc.; while on the hills of the Cantal there were in addition other species of Oaks, with Thorns, Birches, Silver-firs, Spruces, etc.

This was the time of the great explosive eruptions of the volcanoes of Auvergne and the Cantal. To the destructive violence of those eruptions, and the torrents of rain and the floods by which they were accompanied, is due the preservation of so many plant remains; for weighed down by the showers of ashes or swept down by the torrential rains, the trees, branches, and leaves all suffered a common destruction. But although destroyed, the remnants of the disaster were entombed in the mass of ejected scoriæ and ashes; and these latter were often so fine and impalpable as to have received and retain the most delicate impressions of the leaves while yet in a fresh state. It is in such beds, subsequently consolidated (*cinerites*), that the remains of this old land-vegetation have thus come down to us in an admirable state of preservation[2].

Italy. Nowhere else in Europe are Pliocene strata so fully developed. They occupy large tracts in Piedmont and Lombardy, and thence extend on both sides of the central Cretaceous and Eocene range of the Apennines to the south of Italy[3]. They retain usually the same common character

[1] Laugel, 'Bull. Soc. Géol. de France,' 2e sér., vol. xix. p. 709.

[2] Saporta, *Op. cit.*, pp. 314–354.

[3] Brocchi, 'Conchiologia fossile Subapennina'; Cocchi, 'Sulla Geologia dell' Italia Centrale'; Prof. Ponzi, 'Sur la Formation Pliocène des Environs de Rome,' 'Bull. Soc. Géol. de France,' 2e sér., vol. xv. p. 555; C. Mayer, *Op. cit.*, p. 293; and the works of Sismonda and Stoppani.

of grey clays and yellow sands. In Liguria they attain a thickness of 1000 to 1200 feet, and the common shells are *Dentalium sexangulare*, *Turritella subangulata*, *Natica helicina*, *Pleurotoma turricula*, *P. dimidiata*, *Buccinum* (*Nassa*) *semistriatum*, *Columbella tiara*, etc.

At Monte Mario (Rome) the Pliocene has been divided into five zones, with a rich Molluscan fauna of nearly 300 species, amongst which are *Ostrea edulis*, *Corbula striata*, *Cytherea rudis*, *Isocardia cor*, *Limopsis aurita*, *Lucina borealis*, *Mactra triangula*, *Panopæa Faujasi*, *Ringicula buccinea*, *Natica cirriformis*, *Cerithium tricinctum*, *Turritella incrassata*, and other Suffolk-Crag species. In all, Dr. Gwyn Jeffreys considered that about 150 species of the Monte Mario fossils occurs in the Red and White Crags.

Dr. Falconer[1] was of opinion that no locality in Europe is probably so favourably situated for the investigation of the Mammalian fauna of the Pliocene period as the district of the Val d'Arno in Tuscany. These remains are there met with in great abundance and in an excellent state of preservation in the upper lacustrine beds. They comprise *Mastodon Arvernensis*, *Elephas antiquus*, *E. meridionalis*, *Rhinoceros leptorhinus*, *R. Etruscus*, and *Hippopotamus major*, together with species of Tapirus, Equus, Sus, Felis, Machairodus, Hyæna, Bos, Cervus, Antilope, Lagomys, and various small Mammalia.

The Pliocene beds extend into Sicily, where they have been divided by Seguenza[2] into (1) a lower division of light-coloured marls and limestones for which he proposes the term 'Zanclean'; (2) a middle division of blue marls which he correlates with the Plaisancian; and (3) an upper division of yellow sands with the Astian of Mayer. The author shows that the Zanclean contains a fauna of 504 species, of which only eighty-three, or 17 per cent., are recent, whereas in the upper division 32 per cent. are recent; consequently he feels justified in separating this lower division, and associating it with the Tortonian. Although separating it from the Pliocene proper, he considers that it has nevertheless marked relations with that series. It belongs to the group which has been termed by certain geologists Upper Miocene, and by others Mio-pliocene. This division extends into Calabria, and the hill of the Vatican in Rome consists probably of strata of the same age.

The Italian Pliocene is rich in Brachiopods, amongst which the cosmopolitan *Terebratula grandis*, Blum. (or *T. ampulla*, Brocc.) holds a conspicuous position, although this fossil is also met with in the Upper Miocene.

India and Australasia. With the exception of a portion of New

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[1] 'Palæontological Memoirs,' vol. ii. p. 189, etc.
[2] 'Bull. Soc. Géol. de France,' 2e sér., vol. xxv. p. 465.

Zealand, no part of those countries seem to have been beneath the sea-level during the Pliocene period. Dr. Hector refers to this period the marine Kereru beds of the North Island, characterised by the recent *Rotella Zealandica*, and *Dosinea anas* with the extinct *Struthiolaria Fraseri*, *Pleurotoma tuberculata*, and species of Pecten, Buccinum, Chione, Pileopsis, etc. He considers that about 90 per cent. of the species are recent.

At the same time, great torrential rivers were eroding and ploughing the land both in Australia and New Zealand, giving rise to those vast deposits of gravel with plant remains, and rich in gold débris, which now constitute many of the 'deep-leads' of those countries. At this period the volcanic forces in New Zealand were in a state of their greatest activity.

North America. The Sumter Group of North and South Carolina, which contains 40 to 60 per cent. of recent shells, is referred by the American geologists to the Pliocene. It consists of sands and clays overlying the older Tertiaries on the Atlantic and Pacific borders. They contain species of Arca (*A. hians*), Cypræa (*C. pediculus*, Lam.), Conus, Fasciolaria, etc. There are also fresh-water basins in Niobrara, Missouri, and Oregon, with a rich Mammalian fauna of Mastodon (*M. mirificus*), Elephas, Rhinoceros (*Rh. crassus*), Equus, Pliohippus, Felis, Canis, Leptarctus, Procamelus, Megalomeryx, Merycodus, Castor, Hystrix, etc., together with land and fresh-water shells probably of recent species. The great phosphatic deposits of South Carolina may be of this age.

CHAPTER XXVII.

REVIEW OF THE KAINOZOIC OR TERTIARY PERIOD.

IMPORTANCE OF THE BREAK IN THE SUCCESSION OF LIFE AT THE CLOSE OF THE MESOZOIC PERIOD. EXTENSIVE PHYSIOGRAPHICAL CHANGES. MIGRATION CAUSED THEREBY. GENERAL CHARACTERS OF THE VERTEBRATA, INVERTEBRATA, AND PLANTS OF THE TERTIARY PERIOD. APPEARANCE IN TIME AND CHARACTERISTIC GENERA OF THE FISHES, BIRDS, AND MAMMALS IN THE SEVERAL TERTIARY FORMATIONS. SUCCESSIVE DEVELOPMENT. ANCESTRY OF SOME OF THE EXISTING GENERA OF MAMMALIA. THE EARLY GENERALISED TYPES OF PACHYDERMS. THE SUCCESSIVE SPECIALISATION AND DIVERGENCE OF FORMS FROM EOCENE TO PLEISTOCENE TIMES. GRADUAL APPROXIMATION TO EXISTING TYPES. TABLE IX. DISTRIBUTION OF SPECIES.

ANOTHER marvellous change in the life of the European area took place at the close of the Mesozoic period. All the large land and marine Saurians, all the Chambered Shells with the one exception of the Nautilus, several genera of Univalve Shells, a few of Bivalve Shells, some families of Brachiopods, together with a number of Echinodermata and Corals, finally disappeared.

Causes of Change. It is not difficult to understand the dispersion and local extinction of certain classes, for the close of the Cretaceous period was one of extensive continental movements. Throughout Europe the Cretaceous sea-floor was raised, and replaced by new lands or by seas of altered depth. Other areas were submerged or had their old lines of drainage changed, and new rivers and lakes were formed. These oscillations of surface would necessarily be accompanied by changes in the direction of marine currents, in the temperature of the seas, and in the climate of the adjacent lands. Warm areas both of land and sea might become cold, and cold areas warm; and as a consequence all those classes of organic life that could not adapt themselves to the changed physical conditions would be decimated or destroyed.

But it is more difficult to account for the disappearance of the Mesozoic forms in other areas unaffected by similar changes. For although Mesozoic genera and families survive for a time in Southern Europe, and Mesozoic Saurians and Cephalopods linger on in Australasia and America, yet it is only a temporary survival; and they likewise shortly die out. We can only suppose that, adaptability and the facility of migration having a limit, the old types became fewer with each succeeding change of condition, until they ultimately succumbed to the unceasing vicissitudes. And what do we meet with in their place? Such of the marine Mollusca, Echinodermata, Foraminifera, and other creatures that could most readily shift their habitat, survived, subject to certain modifications. But what became of the teeming Mesozoic Ammonites, the marine Saurians, the Lepido-ganoid Fishes? Where are their descendants? With a few exceptions in the case of the last, they left none. In Tertiary times we find their places occupied by other orders of Cephalopoda, by Cetaceans, and by Teleostean Fishes, having no immediate relation to their predecessors. In a similar way, the great terrestrial Reptiles appear to have been succeeded, not by their modified descendants, but by an entirely new class,—by small Mammals of distinct though generalised types, in which, however, some of the Marsupial characters of the few Mesozoic Mammalia are apparent for a time.

It is the same with the Flora. The prevailing Cycads died out, or survived only in some of the warmer regions of the Earth, and were replaced by Angiospermous plants; the Conifers and Ferns continued on with but comparatively little change. This is more easily understood. In the Polar regions the Oligocene or Miocene strata contain an abundant flora, and from a comparison with the contemporaneous floras of more temperate latitudes, there is reason to believe that the vegetation prevalent in Europe during the later Tertiary periods first appeared in northern lands. As the temperature gradually became lower, certain plants passed thence to more southern countries, in the same way, as Edouard Lartet has shown, that at the Quaternary period the increasing cold caused a migration of the large Mammalia from the north to the south of Europe.

Distribution of Life in Kainozoic Times. The following are some of the more general features of the life on the globe during the Tertiary period in the European area:—

Mammalia . . The few small Marsupials of Mesozoic times are now succeeded by the ordinary Mammals, which rapidly increase in numbers and in specialised forms, while the Marsupial types gradually decrease in number, and remain localised in distant areas. Sirenians and Cetaceans appear.

Aves . . . Toothed Birds survive to the Early Eocene. Large wingless Birds appear, gradually succeeded by the forms prevailing at the present day.

Reptilia . . All the larger Reptiles, both of sea and land, except Crocodiles, disappear, as well as the flying Saurians. Serpents appear for the first time. Exclusive of the Chelonians, the number of Reptiles, in the English area, was reduced from forty-one in the Cretaceous to twelve in the Eocene period.

Amphibia . . The old Salamandroid Amphibians are not uncommon, and attain a considerable size in some of the Miocene strata. Batrachians first appear.

Pisces . . . The Teleostean or bony Fishes, which first appeared in later Cretaceous times, now attain a great development. Elasmobranchs continue to be common, while Ganoids decrease.

Mollusca . . Amongst the Cephalopoda,—Ammonites, Turrilites, Scaphites, Hamites, Belemnites, together with ten other genera, disappear; the Nautilus alone of the tetrabranchiates survives, while three new genera of dibranchiates appear. A few genera of Gasteropods disappear, amongst the more important of which is Nerinæa, and amongst the Lamellibranchs, Opis, Gervillia, and Inoceramus; while in both orders a certain number of new genera make their appearance, including Cypræa, Oliva, Cancellaria, Triton, Nassa, Cassis, Haliotis, Purpura, Calyptræa, Patella, Glycimeris, Lutraria, Mya, etc. Most of the land-shells, excepting Helix, Pupa (Carboniferous in America), and a few others, now make their first appearance.

Brachiopoda . Terebratula, Lingula, and a few other genera still survive; Hippurites, Radiolites, Terebrirostra, etc. disappear.

Polyzoa . . . continue numerous; among the most abundant are species of Lepralia, Lunulites, Tubulipora, Discoporella, etc.

Insecta . . As might be supposed from the development of flowering trees and shrubs, the number of Insects now increases enormously, though it is only in a few favoured localities that they are preserved. In the amber-beds of the Baltic they abound. At Œningen the number of species amounts to nearly 900.

Myriapoda and Arachnida Millipedes and Spiders are rare in a fossil state. Twenty-eight species of the latter are, however, recorded from Œningen, and both occur in the amber of the Baltic.

Crustacea . . Of the Entomostraca, the Phyllopods continue to be represented by Estheria, and Ostracods show in increased numbers. Besides Cypridina there are numerous genera of the Cyprididæ and Cytheridæ. Species of Cythere are especially abundant, and many other genera are very common. The Malacostraca are less numerous; and only a few new genera, of which one of the most important is Xanthopsis, make their appearance.

Annelida . . are in diminished force. Ditrupa, Serpula, and Vermicularia are the common genera.

Echinodermata . undergo great changes. Of the Crinoids, only Pentacrinites and Bourgueticrinus survive. Among the Echinoidea,—Holaster, Salenia, Ananchytes, Pseudo-diadema, Cyphosoma, Echinoconus, Micraster, etc., disappear; Cidaris and Hemiaster survive, and Schizaster, Brissus, Clypeaster, Temnopleurus, etc. make their first appearance.

Cœlenterata . Actinozoa. Corals are no longer so abundant as they were in Palæozoic and Mesozoic times. Turbinolia, Solenastræa, Paracyathus, and Trochocyathus are the more common and characteristic genera.

Spongida. The greater number of the abundant Mesozoic Sponges now die out, or are very scantily represented. The boring sponge Cliona is extremely common in Oyster and some other shells.

Foraminifera . Besides the almost universal distribution of Foraminifera in all Marine Tertiaries, the enormous development of Nummulites in Eocene strata in the South of Europe, North Africa, and Upper India, constitutes one of the marked features of Tertiary times.

Plants . . . The development of the Flora is as wonderful as that of the Mammalia. Whereas in the British area there were no angiosperms in Jurassic and Cretaceous times, there were probably above 200 species in Eocene times in England alone. They appeared, however, in Cretaceous times on the Continent, but attained their large development there, as here, at the later period. The genera of most of the existing European trees, including Oak, Poplar, Walnut, Fig, Laurel, Acacia, etc, are met with in early Tertiary strata, combined with Palms and other more tropical forms. Conifers continue to be common in Tertiary as they were in Mesozoic times, but in Europe the Mesozoic Cycads entirely disappear.

Characteristic Genera: Range in Time. With the Invertebrata as well as with the Reptiles, the Tertiary period is marked rather by the absence of old forms than by the introduction of new families. We will now therefore confine attention to the Vertebrata; the Mammalia especially having genera peculiarly characteristic of the several Tertiary formations.

Fishes. The characteristic genera of the Tertiary Elasmobranchii are—Myliobatis, Ætobatis, Pristis, Carcharodon, Galeocerdo, Elasmodus, etc.; and of the Ganoidei—Lepidosteus; while in the Teleostean fishes, the entire families of the Scomberidæ, Gadidæ, Salmonidæ, Clupeidæ, Cyprinidæ, Sparidæ, Mugidæ, etc. make their first appearance.

Birds. The remains of Birds can only be present under certain favourable circumstances. They are therefore comparatively scarce[1].

In the London Clay there is the extraordinary Odontopteryx, a large serrated-billed and probably fish-eating bird, together with a small Vulture, a Kingfisher, and a Heron, and in the Woolwich beds at Croydon there has been found the remains of a species of Gastornis, which closely resembles the Gastornis of the Paris Basin—a large, wingless, wading or anserine bird, of the size of an ostrich.

In the Oligocene there are some birds which differ but little from recent birds, but more of them belong to extinct genera. The *Gryptornis antiquus* of Montmartre shows relations with the African Calaos, and the *Laurillardia* with the Promerops. Gallinaceous birds are also tolerably numerous, together with a few Quails. Altogether, the Gypseous series of Montmartre has yielded sixteen species, consisting of,—

Passeres	5	Gallinaceæ	3	Rallidæ	2
Totanidæ	2	Diurnal Raptores	2	Lamellirostres	2

A curious fact, showing how many forms may escape discovery, was the finding at Montmorency of footprints (but no bones) of seven large species of birds; these measured eight to sixteen inches in length, and therefore were made by Birds exceeding in size the largest Ostrich, but nothing of the birds themselves is known. At Aix and in Auvergne, the eggs and feathers of birds are admirably preserved. There are three species related to the Flamingoes, and one to the Plovers. In Suabia, Cormorants and Buzzards have been found in beds of the same age.

The Miocene strata, especially in Auvergne, are the richest of all in bird-remains. Aquatic birds are there of the most frequent occurrence, including three species of Duck, one Cormorant, one Diver, two Gulls, four Ibises. There are also species of Snipe, Pigeons, Grouse, Sparrows, Parrots, and birds of prey. M. Milne-Edwards considers that the ornithology of these Miocene lakes of Central France is similar to that now represented by certain lakes in Central Africa, with their Pelicans, Ibises, Marabous, Flamingoes, Grouse, Selanganees, Parrots, and Secretary-birds. In the Department of the Allier, sixty-nine species of Birds, mostly of extinct genera, have been discovered, consisting of,—

Psittaci	1	Gruidæ	2	Passeres	14
Diurnal Raptores	6	Ardeidæ	1	Columbidæ	2
Nocturnal Raptores	3	Ciconidæ	5	Gallinaceæ	4
Rallidæ	3	Totanidæ	6	Colymbidæ	1
Lamellirostres	11	Longipennes	6	Totipalmatæ	4

At Sansan, twenty-one species, mostly of extinct genera, occur, belonging to the same families as the above.

In the Faluns of Pontlevoy, a species of Pheasant and a bird of prey have been met with.

[1] For the information respecting fossil birds, we are very largely indebted to M. A. Milne-Edwards's important work, the 'Oiseaux fossiles de la France,' Paris, 1869-71.

In Pliocene strata, birds are scarce. At Montpellier and in Auvergne, only three or four species have been found; at Œningen, three water-birds.

In the Pleistocene strata of France the birds are mostly of recent species, and include Crows, Partridges, Ducks, Geese, Bustards, Vultures, etc.

In Ossiferous Caves proper, one extinct species, with two species now living in colder countries and three species identical with those now living, have been recorded.

Mammalia. In this section I have followed the order adopted by M. Gaudry in his valuable and philosophical works[1] relating to the European Tertiary genera, merely grouping them in accordance with the geological classification adopted in this work, and with a few additions from Owen and other authorities for England. The following list gives the time of the first appearance of the principal genera of the Tertiary Mammalia, but not their range through some of the successive epochs:—

Lower Eocene.	Arctocyon, Coryphodon, Hyracotherium, Pliolophus; Halitherium.
Upper Eocene.	Palæotherium, Paloplotherium, Lophiodon, Pterodon, Cænopithecus, Hyopotamus, Dichobune, Amphicyon, Cynodon, Microchœrus, Sciuroides.
Oligocene. . .	Anoplotherium, Xiphodon, Chœropotamus, Acrotherium, Cainotherium, Amphimeryx, Hyænodon, Adapis, Hyopotamus, Anthracotherium, Hyrachius, Dremotherium, Gelocus, Chalicotherium, with Tapir, Bats, and Squirrels.
Miocene. . . .	Anchitherium, Dinotherium, Mastodon, Oreopithecus, Hyotherium, Machairodus, Taxodon, Dryopithecus, Hyænarctos, Hipparion, Dorcatherium, Rhinoceros, Lagomys, Simocyon, Ancylotherium, Leptodon, Tragoceras, Helladotherium, Ictitherium, Hyæna, Antelope, Squalodon.
Pliocene. . .	Elephas, Felis, Equus, Hippopotamus, Trogontherium, Castor, Bos, Cervus, Bison, Arctomys, Sus, Tapirus, Ursus, Balænodon, Ziphius, Chonoziphius, Balæna, Balænoptera.
Pleistocene. .	Arvicola, Capra, Megaceros, Gulo, Lutra, Ovibos, Spermophilus, Talpa, Vulpes, Sorex, Phoca.

We further gather from the works of M. Gaudry,—

1. That, although few true Marsupials occur in the Tertiary strata of Europe, the Carnivores possessed in the early stages of the Eocene period many Marsupial characters, which indeed were not entirely lost until the close of the Oligocene.

2. That Cetaceans made their first appearance in the Miocene (Upper Oligocene?), but true Whales did not appear until Pliocene times.

3. That Sirenians commenced in Eocene times, but it is not until Miocene and Pliocene times that they occur in any large numbers.

4. That Rhinoceros does not go far back in Tertiary times (Upper Miocene), but was preceded by the Acerotherium of early Miocene, and Palæotherium and Paloplotherium of the Oligocene and Upper Eocene series.

5. That the Tapirs of later Tertiary periods represent the Lophiodon of the Eocene. The Hyrachius of the Oligocene, an animal rare in Europe, seems to be an intermediate form. There is only a very slight difference between the dentition of the Lophiodon and of the Rhinoceros.

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[1] 'Enchainements du Monde Animal,' Paris, 1878, and 'Matériaux pour l'Histoire des Temps Quaternaires,' 1876.

6. That the recent Pig and the various species of Sus of the Pliocene and Upper Miocene were preceded by the Hyotherium in the Lower Miocene and by the Chœropotamus in the Upper Oligocene, to which also the Dichobune of the Upper Eocene is closely related. The Hippopotamus seems to have a closely allied descent.

7. That the oldest ruminants are the Dichobune of the Upper Eocene, and the Xiphodon of the Lower Oligocene—small animals without horns and related both to Pachyderms and Antelopes. Ruminants retained those characters up to Miocene times. The Gelocus and Dremotherium of the Lower Miocene were also hornless animals, but larger and fleeter than those of the Oligocene. In Miocene times Gazelles and Antelopes become very numerous (Tragoceras, Palæoreas, Antelope, etc.), and were provided with horns often large in proportion to the size of the animal. Deer first appear at about Middle Miocene times. The Dicroceras, one of the earliest, had very small simple horns with only two branches. In the Upper Miocene and great part of the Pliocene, the deer had horns with three points, but it was not until the close of the Pliocene and in Pleistocene times that the horns of the deer attained their maximum size and complication. The Forest-bed deer are marked examples of this development. In the above figure the two antlers are reduced from M. Gaudry's figures, but both are drawn to the same scale of one-twentieth of natural size.

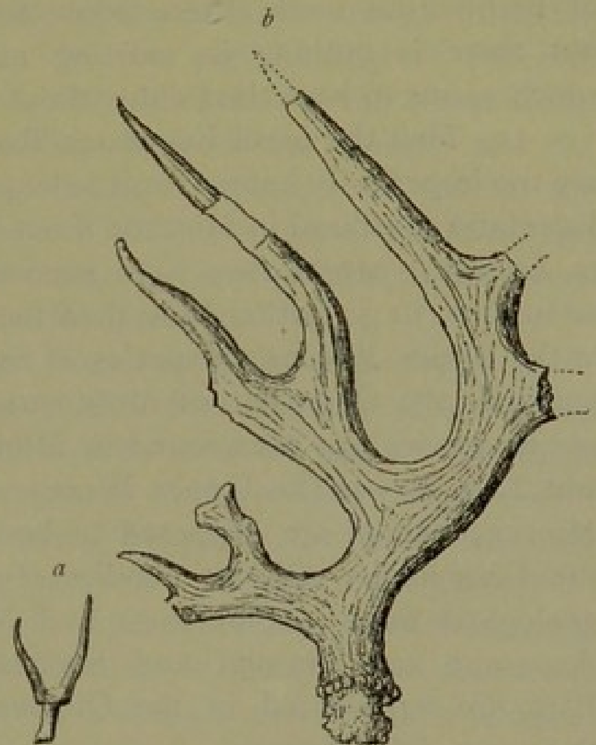

FIG. 212. *a. Dicroceras elegans* (Miocene). *b. Cervus Sedgwickii* (Pleistocene), $\frac{1}{20}$. (After Gaudry.)

8. That there are several links wanting in the genealogy of the Horse in Europe. It is conceivable that it may have been derived from pachyderm ancestors, such as *Paloplotherium minus* or *Pachynolophus siderolithicus* of the Upper Eocene; but the relationship becomes more evident in the *Anchitherium aurelianense* of the Middle Miocene of Sansan; while the *Hipparion gracile* of the Upper Miocene is alike in dentition and many other points with the recent Horse [1].

[1] Professor Marsh has, however, traced the evolution of the Horse in much greater detail in America. Between the Orohippus and Epihippus of the Eocene and the *Equus fraternus* of the Pleistocene about thirty species may be intercalated, of which the principal are the Miohippus and

9. That no Proboscideans nor any of their ancestral forms have been found in Eocene Formations. In Europe they first appear in Miocene times. Whence they came we are as yet ignorant. From the first they were highly and specially organised, and of a size even larger than at present. The recent Elephant rarely exceeds 10 feet in height, but specimens of *Dinotherium giganteum* and of *Elephas meridionalis* have been found which must have stood about 14 feet high. Between the molar teeth of the *Mastodon angustidens*, which present the most perfect type of omnivorous teeth, and those of the Elephants, the most perfect type of herbivorous teeth, there seem to be almost insensible gradations[1]; but there is nothing in existing nature to resemble the Dinotherium, which seems to have died out without leaving any posterity[2].

10. That the fossil Edentates, Rodents, Insectivores, and Cheiropteres are too imperfectly known for it to be possible to follow their evolution. The Edentates appeared in Miocene if not in Eocene times, but are now extinct in Europe, whereas they have survived in America, though they do not seem there to go farther back than the Pliocene period. Rodents appeared in the Upper Eocene: a species of Squirrel and one of Myoxus have been found in the Oligocene of Montmartre; a Beaver closely resembling the recent species has been found in Miocene and Pliocene strata; Porcupines and Lagomys in the Upper Miocene, and Hares in the Pliocene. Other Miocene genera are supposed to be allied to the Rat of America and to the Chinchilla. All the families of the Insectivores are represented in geological times; Hedgehogs and Moles are found in the Miocene of Auvergne and Sansan; and Shrews in the Miocene of Sansan. The Bats are represented in the Oligocene by the *Vespertilio aquensis* and the genus *Rhinolophus*.

11. That the ancestors of the recent Carnivora show relationships between genera which are now widely separated. The Amphicyon of the Eocene had the dentition of the dog and the plantigrade characters of the bear. The Hyænarctos of Sansan combined characters of the hyænas and bears. At present the Civets are perfectly distinct from the Hyænas, but the Ictitherium (Fig. 203) of Pikermi possesses characters

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Anchitherium of the Miocene, and the Pliohippus and Hipparion of the Pliocene. 'Notice of new Equine Mammals from the Tertiary Formation,' 'Amer. Journ. Arts and Sc.,' vol. vii, March, 1874, and vol. xii, July, 1876.

[1] Dr. Falconer's paper on the Mastodon and Elephant, 'Quart. Journ. Geol. Soc.,' vol. xiii. p. 307; vol. xiv. p. 81; vol xxi. p. 253.

[2] There is an extremely interesting series of sections of the teeth of Dinotherium, Mastodon, Elephant (Stegodon, Loxodon, Euelephas), in one of the cases of the British Museum (Natural History gallery), which exhibits in a striking manner the gradual deepening of the open valleys between the ridges of the teeth, the filling of them up with enamel, and the successive elongation and approximation of the plates, ending finally in the narrow-plated teeth of *E. primigenius*.

common to both genera. On the other hand, the Pliocene *Hyæna Perrieri* is allied to the recent Spotted Hyæna and the *Hyæna Arvernensis* of Auvergne to the Striped Hyæna of Africa. The terrible Carnivore Machairodus, with its huge sabre-shaped teeth, seems to have had no descendants.

12. That the Quadrumana were represented in Oligocene times by some intermediate species, connecting them with the earlier Pachyderms. In the Apes it was the Adapis and Plesiodapis, and in the Monkeys the Cebochœrus and Oreopithecus. The ordinary Monkeys and the Anthropoid Apes first appear about the middle of the Miocene series. In Later Miocene times they were numerous. In the one locality of Pikermi, M. Gaudry found the remains of twenty-five individuals of the *Mesopithecus Pentelici* (Fig. 204), a creature intermediate between the Monkey and the Gibbon, and therefore, like the Pliopithecus of Sansan, related to the Anthropoid Apes. But a Miocene Ape of still more specialised form, and approaching in size and several other characters near to Man, is the Dryopithecus of Saint-Gaudens in the Haute Garonne.

The geological lesson to be learnt from the study of the fossil Mammalia is, as M. Gaudry remarks, that in the older Tertiary (Eocene and Oligocene) they had generalised characters, with an absence of those extreme divergences which the higher animals of the present day possess—that there were then no true Ruminants, Solipedes, Proboscideans, nor Quadrumana. In the Miocene, existing genera became more numerous; Marsupials were then nearly extinct in Europe; some Pachyderms approached to the Solipedes; and some Ruminants had the true characters of that order. In the Upper Miocene, the Mammalia reached their apogee; there were no longer any traces of Marsupials in Europe; the higher animals abounded under the true types of Ruminants, Solipedes, Edentates, Proboscideans, Carnivora, and Quadrumana, but there were still many genera slightly differing from existing genera. In the Pliocene, all the mammals belonged to the same genera, but not to the same species, as those of the present day.

TABLE IX.—SHOWING THE DISTRIBUTION OF THE ORGANIC REMAINS IN THE MAIN DIVISIONS OF THE TERTIARY OR KAINOZOIC (INCLUSIVE OF THE NEXT OR QUATERNARY SERIES) IN THE BRITISH AREA.

		Eocene.		*Oligocene.*	*Pliocene.*	*Quaternary* or *Pleistocene.*
		Lower.	Upper.			
		Lower Bagshot Sands. London Clay and Basement Bed. Woolwich-and-Reading Beds. Thanet Sands.	Barton Clay. Upper Bagshot Sands. Bracklesham Sands.	Hempstead and Bovey Tracey Beds. Bembridge, Brockenhurst, and Headon Hill Beds.	Chillesford Beds. Norwich and Red Crag. White (Coralline) Crag.	Raised Beaches. Loess and Valley Gravels. Caves, etc. Glacial Deposits. Westleton Shingle and Forest-Bed.
	Mammals ...	7	7	10	57[1]	130
	Birds	6	1	...	...	37
	Reptiles... ...	21	22	...	...	...
	Amphibians ...	...	...	...	...	...
	Fishes	91	45	...	27	14
Mollusca	Cephalopods	10	3	...	...	...
Mollusca	Pteropods ...	...	...	...	1	...
Mollusca	Heteropods ...	...	...	...	...	...
Mollusca	Gasteropods ...	172	476	52	416	302
Mollusca	Lamellibranchs	146	239	32	258	184
Molluscoidea	Brachiopods...	2	1	...	9	3
Molluscoidea	Polyzoa... ...	4	4	8	139	23
	Insects	...	...	...	...	...
	Arachnida and Myriapoda	...	...	...	...	...
	Crustaceans ...	43	21	11	40	165[2]
	Worms (annelids) ...	10	8	...	18	14
	Echinoderms	17	7	...	30	18
Cœlenterata	Corals	16	43	10	12	7
Cœlenterata	Sponges ...	...	...	...	...	5
	Foraminifera...	33	10	...	95	73
	Plants	127	48	69	1	103
		705	935	192	1103	1078

[1] Inclusive of 26 marine species.

[2] Inclusive of 148 Entomostraca.

PLATE XIII.

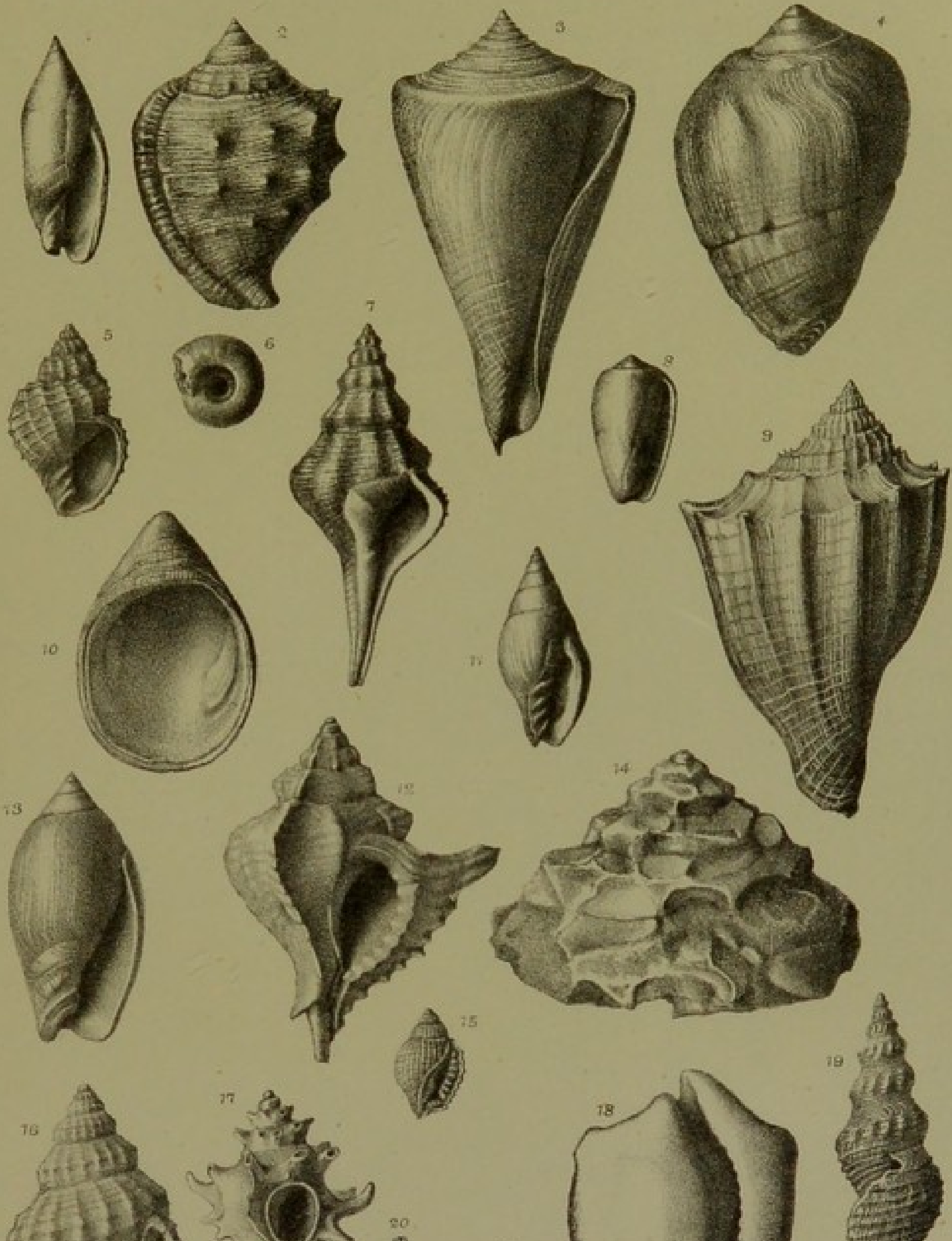
TERTIARY MOLLUSCA.

Eocene.

1.	Ancillaria buccinoides, *Lam.* ...	*Barton and Bracklesham.*
2.	Cassidaria coronata, *Brand.*	*Barton and Bracklesham.*
3.	Conus deperditus, *Brug.*	*Barton and Bracklesham.*
4.	Pseudoliva fissurata, *Desh.*	*London Clay, Woolwich and Reading.*
5.	Cancellaria evulsa, *Brand.*	*Barton.*
6.	Bifrontia Laudinensis, *Lam.*	*Barton and Bracklesham.*
7.	Fasciolaria uniplicata, *Lam.*	*Barton and Bracklesham.*
8.	Marginella ovulata, *Lam.*	*Barton.*
9.	Voluta Solandri, *Edw.*	*Barton.*
10.	Hipponyx cornucopia, *Lam.*	*Barton and Bracklesham.*
11.	Mitra labratula, *Lam.*	*Barton.*
12.	Murex asper, *Brand.*	*Barton and Bracklesham.*
13.	Oliva Branderi, *Sby.*	*Barton.*
14.	Phorus agglutinans, *Lam.*	*Barton and Bracklesham.*
15.	Strombus Bartonensis, *Sby.*	*Barton.*
16.	Triton argutus, *Sby.*	*Barton.*
17.	Typhis pungens, *Brand.*	*Barton.*
18.	Cypræa tuberculosa, *Sby.*	*Bracklesham.*
19.	Pleurotoma rostrata, *Brand.*	*London Clay and Barton.*
20.	Terebellum sopitum, *Brand.* ...	*Barton.*
21.	Ovula retusa, *Sby.*	*London Clay.*
22.	Cultellus affinis, *Sby.*	*London Clay, Bracklesham, and Barton.*
23.	Trigonocœlia (*Nucula*) deltoidea, *Lam.*	*Barton and Headon.*
24.	Limopsis scalaris, *Sby.*	*Barton.*
25.	Crassatella sulcata, *Sol.*	*Bracklesham and Barton.*

Plate XIII.

TERTIARY MOLLUSCA:- EOCENE.



G. M. Woodward del et lith.

Prestwich's Geology, II.— Clarendon Press.

PLATE XIV.

TERTIARY MOLLUSCA.

Oligocene.

1.	Pleurotoma subdenticulata, *Goldf.* ...	*Brockenhurst.*
2.	Neritina (Nerita) aperta, *Sby.*	*Headon.*
3.	Murex sexdentatus, *Sby.*	*Headon.*
4.	Voluta Rathieri, *Héb.*	*Hempstead.*
5.	Cerithium plicatum, *Lamk.*	*Hempstead.*
6.	Rissoa Chastelli, *Nyst.*	*Hempstead.*
7.	Melania muricata, *S. Wood.*	*Bembridge.*
8.	Cytherea incrassata, *Sby.*	*Headon and Brockenhurst.*
9.	Ostrea callifera, *Lamk.*	*Hempstead.*
10.	Ostrea velata, *S. Wood.*	*Headon.*
11.	Corbula subpisum, *D'Orb.* (vectensis, *Forb.*)	*Hempstead and Brockenhurst.*

Pliocene.

12.	Cyprina rustica, *Sby.*	*White and Red Crags.*
13.	Nucula Cobboldii, *Sby.*	*Red and Norwich Crags.*
14.	Astarte Burtini, *Lajonk.*	*White and Red Crags.*
15.	Corbula striata, *Walk.*	*White and Red Crags.*
16.	Corbulomya (Corbula) complanata, *Sby.* ...	*Red Crag.*
17.	Panopæa Faujasii, *Mén.*	*White and Red Crags.*
18.	Natica hemiclausa, *Sby.*	*Red and Norwich Crags.*
19.	Cerithium tricinctum, *Bosc.*	*Red and Norwich Crags.*
20.	Pleurotoma turricula, *Mont.*	*Red and Norwich Crags.*
21.	Nassa incrassata, *Müll.*	*White and Red Crags.*
22.	Scalaria frondicula, *S. Wood.*	*White or Coralline Crag.*
23.	Trophon alveolatum, *Sby.*	*White and Red Crags.*
24.	Pyrula acclinis, *S. Wood.*	*White and Red Crags.*

Plate XIV.

TERTIARY MOLLUSCA.

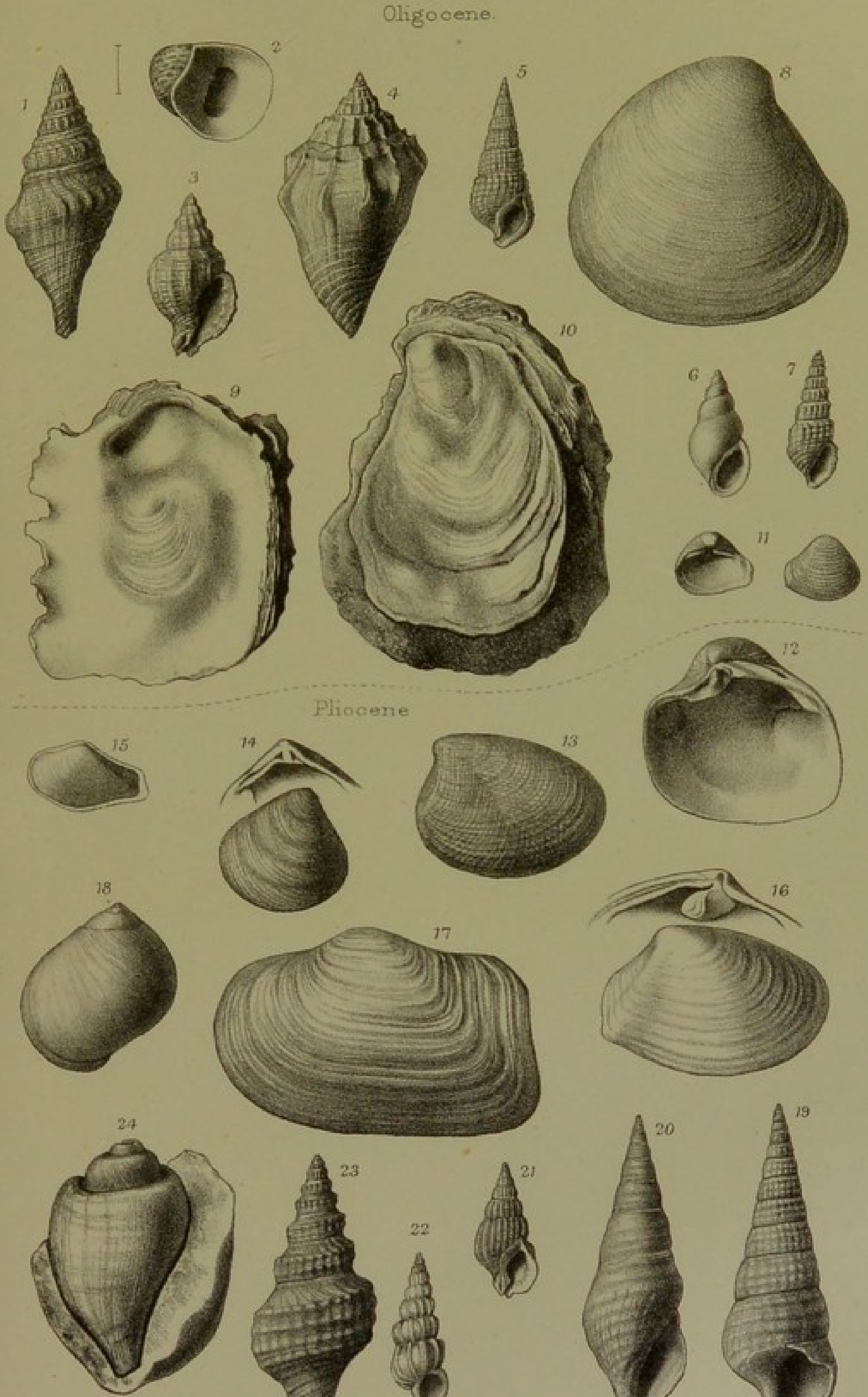


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PLATE XV.

TERTIARY CEPHALOPODA, ECHINODERMATA, ETC.

Eocene.

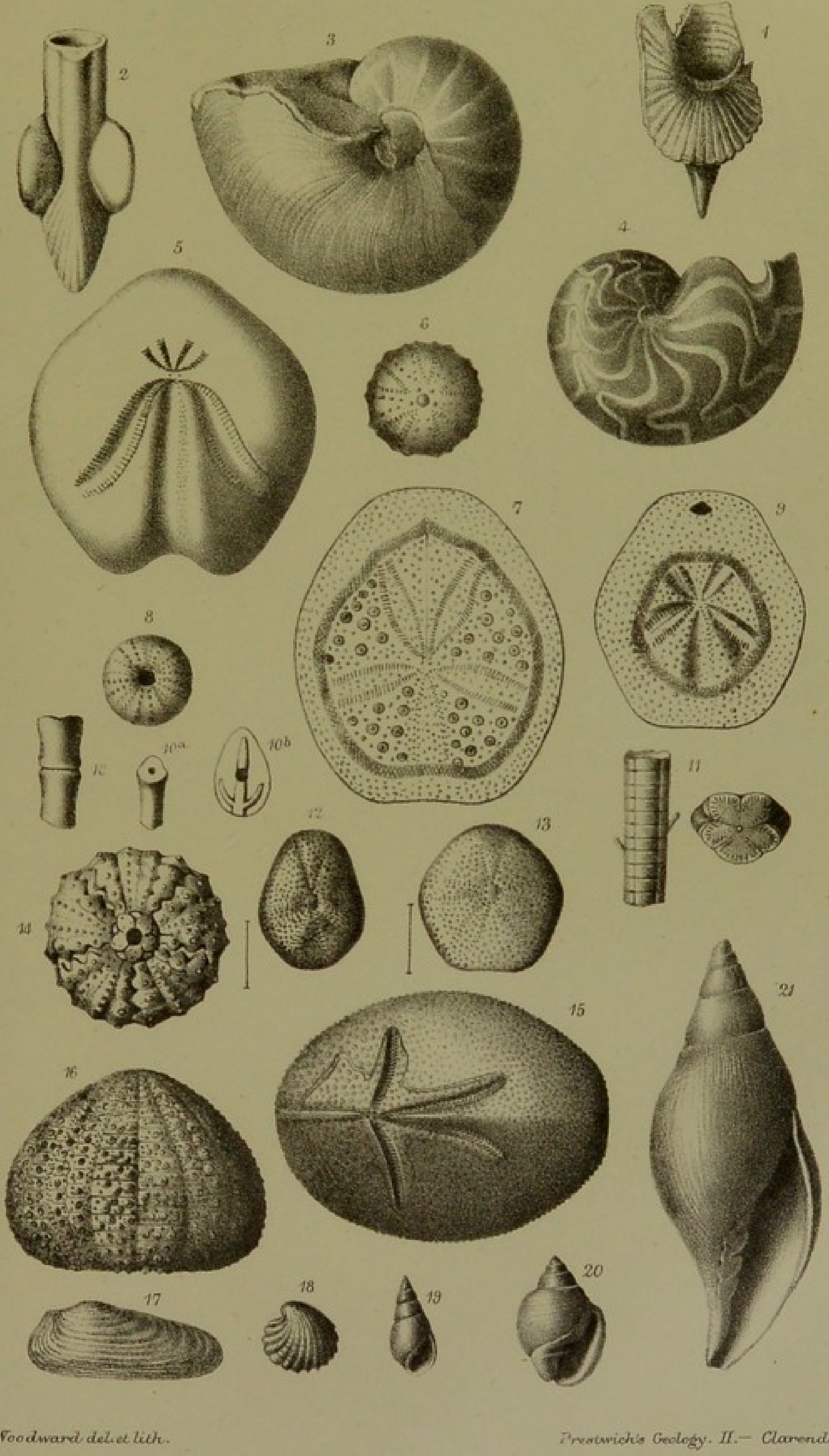
1.	Belosepia Cuvieri, *Voltz.*	*Bracklesham.*
2.	Beloptera belemnitoidea, *Blainv.*	*Bracklesham.*
3.	Nautilus centralis, *Sby.*	*London Clay.*
4.	Aturia zic-zac, *Sby.*	*London Clay.*
5.	Schizaster D'Urbani, *Forb.*	*Barton.*
6.	Cœlopleurus Wetherelli, *Forb.*	*London Clay.*
7.	Eupatagus Hastingsiæ, *Forb.*	*Barton.*
8.	Echinopsis Edwardsii, *Forb.*	*Bracklesham.*
9.	Hemiaster Branderianus, *Forb.*	*London Clay and Barton.*
10.	Graphularia Wetherelli, *Milne Edw.*	*London Clay.*
11.	Pentacrinus sub-basaltiformis, *Forb.*	*London Clay.*

Pliocene.

12.	Echinocyamus pusillus, *Forb.*	*Red Crag.*
13.	Echinocyamus hispidulus, *Forb.*	*White Crag.*
14.	Temnechinus excavatus, *Forb.*	*White Crag.*
15.	Brissus Scillæ, *Agass.*	*White Crag.*
16.	Echinus Woodwardi, *Desor* (Lamarckii, *Forb.*) ...	*White Crag.*
17.	Glycimeris angusta, *Nyst.*	*White Crag.*
18.	Verticordia cardiiformis, *Sby.*	*White Crag.*
19.	Odostomia plicata, *Montf.*	*White Crag.*
20.	Ringicula ventricosa, *Sby.*	*White Crag.*
21.	Voluta Lamberti, *Sby.*	*White Crag.*

Plate XV.

TERTIARY ECHINODERMATA, CEPHALOPODA, ETC.



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CHAPTER XXVIII.

THE QUATERNARY OR PLEISTOCENE PERIOD

THE PRE-GLACIAL AND GLACIAL EPOCHS.

NO DEFINITE BASE-LINE. USE OF THE TERM 'QUATERNARY.' THE WESTLETON SERIES: THE FOREST, ELEPHANT, AND FLUVIO-MARINE BEDS OF NORFOLK. THE SANDS AND SHINGLE OF SUFFOLK. THE GLACIAL SERIES. THE LOWER BOULDER-CLAY, CONTORTED DRIFT, SANDS, AND UPPER BOULDER-CLAY OF NORFOLK. THE GLACIAL SERIES OF LINCOLNSHIRE. THE BRIDLINGTON CRAG. EVIDENCE OF LAND GLACIATION. GLACIATED SURFACES OF DURHAM, ETC. THE GLACIAL SERIES OF THE WEST OF ENGLAND, LANCASHIRE, CHESHIRE, DERBYSHIRE. LOWER TILL. THE FOSSILIFEROUS SANDS AND GRAVELS. THE SHELL-BEDS OF MACCLESFIELD AND MOEL TRYFAEN. UPPER BOULDER-CLAY. NORTHERN ROCK-DÉBRIS. SCOTLAND. SHELL-BEDS. TILL. BOULDER SANDS AND GRAVELS. LATER BRICK-EARTHS. ARCTIC MOLLUSCA. ERRATIC BLOCKS. SILURIAN BLOCKS ON LIMESTONE PEDESTALS. THICKNESS OF THE ICE-SHEET. GENERAL SOUTHWARD FLOW INDEPENDENT OF MINOR IRREGULARITIES OF SURFACE. SCOTTISH AND ENGLISH CENTRES OF DISPERSION. ROCHES 'MOUTONNÉES.' LATER RADIATING GLACIERS.

Absence of a Base-line. There is no strongly marked break, either stratigraphically or palæontologically, to fix clearly the commencement of the Quaternary period. It was marked, however, by slight local emergences, which gave to Europe the outlines which, with few modifications, it has at the present day, and more especially by the peculiar climatal conditions which then began to prevail throughout both hemispheres. The base-line therefore is somewhat arbitrary. I have placed it[1] at the top of the Chillesford Clay when the sea-area was converted into the land on which the trees of the 'Forest-bed' grew, and the animals of the 'Elephant-bed' lived. The plants, together with the marine and terrestrial mollusca of these beds, are almost all of existing species; and, although so many of the mammalia are of extinct forms, there were then introduced the larger number of the ordinary animals now living in this country and in other parts of temperate Europe. This constitutes the most striking palæontological feature of the time; and further, it is in some of the later deposits of this period that the remains of Man

[1] It may be a question whether it might not be placed at the base of the Red Crag, for whereas in the White (Coralline) Crag the proportion of extinct to recent species is 16 per cent., in the Red Crag it is only 7·77 per cent., or a difference of 8·23 per cent.; while between the Red Crag and the Glacial Beds the difference is considerably less.

and of his handiwork have been discovered in association with the latest of the extinct mammalia.

The exact geological time of Man's first appearance in these latitudes is yet an unsettled question. In any case, it would appear that it was the peculiar climatal conditions of this period that led in the main to the present distribution of the existing faunas and floras, with which man is so intimately associated.

For these reasons I think the term 'Quaternary' useful and fitting. I retain the term 'Pleistocene' also to show its sequence to the Tertiary series. The objection has been raised that being restricted to so small a group of strata, and to so short a period of geological time, its value in these respects bears no comparison with the other great primary divisions. But on these grounds alone, neither will the Tertiary compare with the Secondary, nor the latter with the Palæozoic Series, although we have before (Vol. I. p. 61) shown that the relative dimensions of these several series afford no criterion of the time occupied in their formation. Their value is to be judged of from the importance of their life-history, and of those great physical changes which gave a special stamp to the times.

THE WESTLETON SERIES.

At the base of the Quaternary deposits, and coextensive with the Glacial series of the Eastern Counties, are the 'Westleton Sands and Shingle' of Norfolk and Suffolk; a variable series representing marine or estuarine conditions in the latter area, and land, marsh, and fluvio-marine conditions in the former. On the Norfolk coast it is divisible into several beds.

The Forest- and Elephant-Beds. The emergence of the sea-bed at the close of the Chillesford period led to the formation, in the Norfolk area, of a tract of low land, on parts of which flourished trees of considerable size. The stools of these trees are yet standing in the position in which they grew (frequently with their trunks alongside), and the roots penetrating down into the Chillesford Clay. The best exhibition of these old trees may be seen at low water on the shore at Happisburg and Bacton, when storms have removed the overlying beach and sands. To this zone the name of 'Forest-bed' has been given.

Associated with the Forest-bed is a bed of sandy clay and gravel, containing numerous mammalian remains, known as 'The Elephant-bed.'

The trees consist of few species. It is of interest to notice amongst them the common Norway Spruce, which afterwards disappeared in this country, and has been re-introduced from Norway within the historical period. Other adjoining portions of this emerged land seem to have remained in a marshy state, not suited for the growth of large timber, but covered with a smaller vegetation of water-plants, of which little more than the rootlets or some seeds now remain. The fauna and flora of these beds, which are rarely more than 5 to 6 feet thick, are of singular interest, and have recently been exhaustively investigated by the officers of the Geological Survey[1].

It is very remarkable to find in the Forest-bed, and under the whole of the Boulder-clay series, trees and plants closely allied to those now commonly living in Norfolk, with shells also of species now teeming in its ponds and marshes, yet with mammalia of large extinct forms, associated, however, with other species yet surviving.

The enlarged list given by Mr. Clement Reid of the Forest-bed flora now includes three Cryptogamic, five Gymnospermous, eighteen Monocotyledonous, and four Angiospermous plants. Amongst these some of the most common are,—

Osmunda regalis (*Royal Fern*).
Pinus sylvestris (*Scotch Fir*).
" abies (*Spruce Fir*).
Taxus baccata (*Yew*).
Potamogeton crispus (*Curly Pond-weed*).
" heterophyllus (*Various-leaved Pond-weed*).
Alisma plantago (*Water-plantain*).
Scirpus lacustris (*Lake-rush*).
Quercus robur (*Oak*).
Fagus sylvatica (*Beech*).
Salix, 3 sp. (*Willow*).
Prunus spinosa (*Sloe*).
Hippuris vulgaris (*Mare's-tail*).
Trapa natans (*Water-Chesnut*).
Nuphar lutea (*Yellow Water-lily*).
Ranunculus aquatilis (*Water-crowfoot*).
Thalictrum flavum (*Meadow-rue*).

The wood and cones of the conifers[2] are of common occurrence. Leaves of the willow and birch occur rarely in ironstone nodules[3]. The greater number of the marsh and water plants have only been recognised by their seeds, which Mr. Reid obtained by carefully washing the clay, and then sifting the contents.

The list of mammalia of the Elephant-bed, as amended by Mr. E. T. Newton, now embraces nine Carnivores, eighteen Ungulates, three Rodents, three Proboscideans, three Cetaceans; together with one Bird and six Fishes.

Amongst the principal species are,—

Ursus spelæus, *Blum.*
Gulo luscus, *Linn.*
Tricheus Huxleyi, *Lamk.*
Equus caballus fossilis, *Rütim.*
Rhinoceros Etruscus, *Falc.*
Hippopotamus major, *Ow.*
Trogontherium Cuvieri, *Ow.*
Castor Europæus, *Ow.*
Cervus Sedgwickii, *Falc.*
" Polignacus, *Rob.*
" verticornis, *Dawk.*
Elephas antiquus, *Falc.*
" meridionalis, *Nesti.*
" primigenius, *Blum.*
Monodon monoceros, *Linn.*
Delphinus delphis, *Linn.*

[1] Mr. Clement Reid in Mem. Geol. Survey, 'Geology of Cromer,' 1882; and 'Trans. Norfolk Nat. Hist. Soc.,' January, 1886; Mr. E. T. Newton, 'The Vertebrata of the Forest-Bed Series,' 1882. These and the associated beds were first described by Mr. Samuel Woodward in 1833, and later by Mr. John Gunn, in his 'Geology of Norfolk,' and various other writers.

[2] Amber is also found all along the east coast; Mr. Reid thinks it is washed up out of an older bed, as the amber-producing conifers have not been recognised in the Forest-bed.

[3] At Bacton I have seen the branches and twigs of the conifers forming in places a loose matted mass two to three feet thick.

The Westleton Sands and Shingle. A series of thin beds of laminated and carbonaceous clays, sand, and gravel, of fluvio-marine origin, and often fossiliferous, overlies the Forest- and Elephant-beds. In 1861 I gave the section of these beds as seen at Mundesley, and subsequently showed that they were synchronous with the Westleton sands and shingle of Suffolk[1]. The total thickness of the group, lying at the base of the cliff at Mundesley, does not exceed 20 to 25 feet. The fresh-water beds are mostly at the base of the deposit. On the top of this series at Runton and Sherringham is a brown clay with marine shells *in sitû*, discovered by Mr. Trimmer. In it *Leda myalis* and *Mya truncata* are abundant. The following are amongst the most common species of this series :—

Unio pictorum *Linn.*
Pisidium amnicum, *Müll.* Pl. XVI, fig. 14.
Bythinia tentaculata, *Linn.* Pl. XVI, fig. 21.
Valvata piscinalis, *Müll.* Pl. XVI, fig. 20.
Succinea oblonga, *Drap.* Pl. XVI. fig. 22.
Helix hispida, *Linn.* Pl. XVI. fig. 25.
Planorbis spirorbis, *Linn.* Pl. XVI, fig. 17.
Limnæa truncatula, *Müll.*
Tellina Balthica, *Linn.*
Cardium edule, *Linn.*
Mytilus edulis, *Linn.*
Littorina rudis, *Maton.* Pl. XVI, fig. 12.
Purpura lapillus, *Linn.*
Mya truncata, *Brod.* Pl. XVI, fig. 2.
Leda myalis, *Couth.*
Astarte borealis, *Chemn.* Pl. XIV. fig. 5.

With the exception of *Platax Woodwardi* (which may have been derived from the Crag) the fish-remains are all of recent species.

Amongst the mammalia peculiar to the upper clay-beds Mr. Newton has recognised *Martes sylvaticus,* Nils., *Arvicola glareolus*, Schr., *A. arvalis*, Pall., *Talpa Europæa*, Linn., and *Myogale moschata*, Linn.; together with two snakes, the frog, the toad, and five fishes, all of recent species. The *Arvicola arvalis* is extinct in England, but is living in middle Europe and Western Siberia, the *Myogale moschata* is now confined to the region between the Danube and the Volga. In another bed of clay, occurring occasionally at the top of this series, *Hypnum turgescens,* leaves of *Betula nana* and *Salix polaris,* and bones of Spermophilus have been found, though very rarely.

Further southward this deposit changes in its character. The fresh-water remains and the argillaceous beds disappear, and are replaced by white sands and shingle, which in the neighbourhood of Southwold, Henham, and Westleton (whence the name) are from 30 to 60 feet thick. They there consist of beds of flint pebbles as well rounded as those of Eocene age of Blackheath and Addington, with others of white quartz and chalcedony, and a few old-rock pebbles of quartzite, etc. These beds are usually without fossils. This may be due to a percolation of the surface-waters, for in the neighbourhood of Southwold, where the sands and shingle are sometimes concreted into solid bands by the peroxide of iron, there

[1] I retain that term because I look upon the Forest-bed as only a local accident, and confined to a very limited area.

are seams full of the casts of *Mytilus edulis* in all stages of growth, with *Cardium*, *Littorina*, and *Natica*.

The Glacial Series on the Coast of East Norfolk, where it is very fully developed, and immediately succeeds the Westleton beds, consists in descending order of—

1. Upper unstratified chalky Boulder-clay.
2. Fossiliferous sands and gravel (the 'Middle Glacial' of Messrs. Wood and Harmer).
3. Contorted boulder-clay and laminated clays.
4. Lower unstratified grey boulder-clay.

The Lower Boulder-clay does not exceed 10 to 25 feet in thickness, and rests on a slightly eroded surface of the Westleton beds (including the

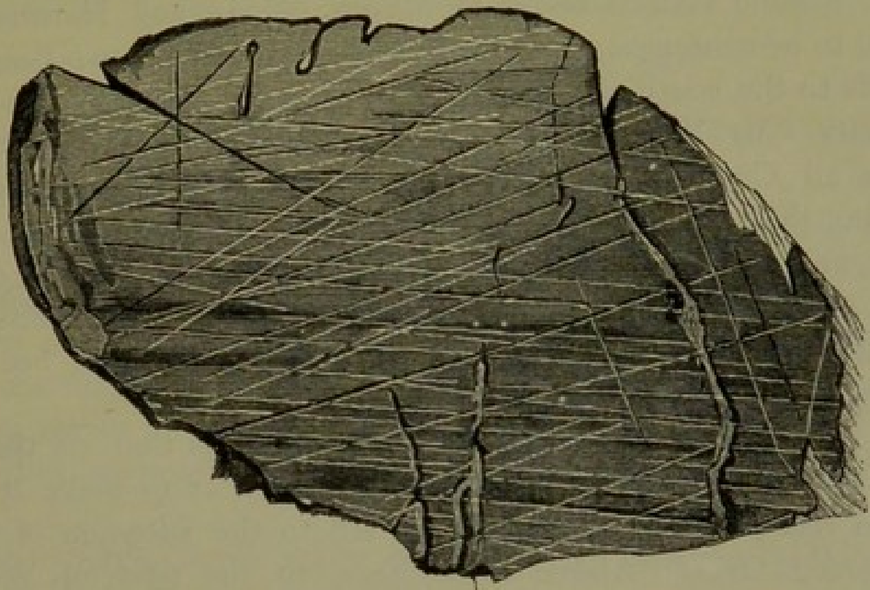

FIG. 213. *An ice-scratched fragment of rock from a terminal moraine.*

'Laminated Beds' of Mr. Gunn). It contains worn and ice-scratched fragments of Jurassic rocks and of hard Chalk (of Yorkshire?), with boulders, also glaciated, of crystalline granitic, and basaltic rocks. The boulders vary in size from one foot to five or six feet in diameter, and seem to have been derived from Scandinavian rocks; but a thorough examination of them has yet to be made[1]. They are scattered sparsely over part of East Norfolk, and are only comparatively abundant in a small tract at Happisburgh. Fragments of *Cyprina Islandica* and *Mya arenaria* are common; entire specimens of *Tellina Balthica* and *Cardium edule* are also not rare in this clay. It was probably a marine silt, deposited in a sea covered with floating ice—both from coast and glacier—laden with débris from the shores and mountains of Norway. Other geologists, however, consider it to be the product of land-glaciation.

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[1] Dr. Archibald Geikie could discover no Scotch rocks amongst them.

The Lower Boulder-clay (sometimes divided into two beds) is succeeded in the Mundesley district by finely laminated, light-coloured, unfossiliferous sandy clay, passing up into sands, gravel, and chalk-rubble, which last ultimately replaces the others as the beds trend northwards. This chalk-rubble is remarkable for the number and size of the boulders of chalk it contains. According to Mr. Reid, one of them in the cliffs at Runton measures 180 yards in length. It also contains débris from the Kimmeridge Clay, Lias, Trias, and Carboniferous rocks, together with boulders of quartzite, granite, and crystalline rocks, similar to those in the Boulder-clay beneath.

Irregularly scattered over these chalky beds, between Cromer and Weybourne, are roughly stratified sands and gravel, in places full of fragments of shells, but with only a few entire specimens. These fossiliferous sands form the 'Middle Glacial beds' of Messrs. Wood and Harmer and are considered to be contemporaneous with those between the two Boulder-clays in the cliffs to the south of Yarmouth. The shells there are also generally in fragments. Mr. Wood nevertheless has determined about 100 species. They are all Crag species, with the exception of one Venus and a Loripes, and the only entire shells are specimens of *Nassa reticosa*, *Anomia ephippium*, and species of *Dentalium* and *Scalaria*. Mr. Wood considered it to be a contemporaneous fauna; but Mr. Clement Reid thinks that, in Norfolk at all events, a large proportion of the shells have been derived from underlying Crag-beds.

It is these loams, chalk-rubble, and shelly beds that, on the coast of North Norfolk, have been so powerfully contorted as to make it in places difficult to recognise the sequence, and led to the adoption of the name of 'Contorted Drift.' Above these beds, to the west of Weybourne, Mr. Horace B. Woodward places another Boulder-clay, to which succeed the great heaps of coarse flint gravel, forming in that area the top of the Glacial series.

The Glacial Series of Lincolnshire consists, according to Messrs. Wood and Rome[1], of a great mass of unstratified clay, the result of land-glaciation, overlain by boulder-gravel, and then by a purple boulder-clay. These are the broad divisions; here, however, as in Norfolk, the beds vary very much in their details as in their thickness, which generally does not exceed 50 to 100 feet. When, however, they fill depressions, they acquire a much greater thickness. A case is mentioned by Dr. J. Geikie on the authority of Mr. S. B. J. Skertchly, of a boring at Boston, where the surface is only 20 feet above the sea-level, which passed through 563 feet of these beds without reaching the bottom of the series.

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1 'Geol. Mag.' Decade 2, vol. viii. p. 535, 1881; see also Messrs. Dakyns and Fox Strangways on the Geology of Bridlington Bay, in 'Mem. Geol. Survey,' 1885.

Alluvial beds, 24 ft.; Boulder-clay, 440 ft.	464 feet.
Sand and gravel, 24 ft.; clay, 7 ft.; gravel, 5 ft.	36 "
Boulder-clay, 20 ft.; coarse gravel, 19 ft.	39 "
Clay, 7 ft.; white sand, 11 ft.; brown loam, 6 ft.	24 "
Total	563 feet.

Bridlington Sands or Crag. At, or near the base of the Boulder-clay at Bridlington, there occur one or more patches of argillaceous green sands, of small thickness, containing a considerable number of shells in a fair state of preservation. The recent researches of Mr. Lamplugh[1] have led him to conclude that these patches are not *in sitû*, as at first supposed, but are masses torn off from the original bed, and re-deposited in the Boulder-clay. One hundred and eleven species have been determined, of which the following are some of the principal:—

Astarte compressa, *Mont.*
" borealis. *Chemn.*
Leda pernula, *Müll.* Pl. XVI, fig. 8.
Cardium Grœnlandicum, *Chemn.*
Tellina Balthica, *Linn.* Fig. 215, *a*, *b*.
Cyprina Islandica, *Linn.*
Saxicava rugosa, *Linn.*
Pholas cristata, *Linn.*
Trophon clathratum, *Linn.* Pl. XVI, fig. 10.
Littorina rudis, *Maton.*
Fusus Spitzbergensis.
Natica affinis, *Gmel.* Pl. XVI, fig. 11.

According to Mr. Etheridge, there are six extinct species of shells; but four of these were considered by the late Dr. J. G. Jeffreys to be doubtful species or varieties. This reduces the number to under two per cent. of recent forms on the whole, a proportion which would indicate, as E. Forbes supposed, that these beds are newer than the Norfolk Crag.

If these masses have really been detached from an older bed, they could hardly have been removed far, nor can there be wide limits for its age. It may represent a deposit equivalent to the upper or more arctic portion of the Chillesford Clay, or it may be the marine equivalent of the Westleton beds; but, owing to the absence of superposition, and the limited fauna of the latter two, this can only be surmised. The differences of condition must be taken into account. A large number of the marine species in the Norfolk and Suffolk beds are, however, common to the Bridlington beds.

At Kelsea Hill, near Hull, is another fossiliferous bed; but in this case it overlies the Lower-Boulder Series, and underlies the Purple Boulder-clay. It consists of a coarse subangular flint gravel, regularly stratified, and containing carbonaceous débris and pebbles of foreign rocks. The shells, which are numerous, and of forty species, are all, with one exception, identical with species now living in the German Ocean. That exception is the *Cyrena* (*Corbicula*) *fluminalis.* The shells have the

[1] 'Quart. Journ. Geol. Soc.,' vol. xxiv. p. 146.

appearance of having been dead shells cast up on a shingle-bank. The *Cyrena* is the only river-shell, and is in a better state of preservation [1].

Evidence of Glaciation. Owing to the soft nature of the strata in these districts, there are few glaciated surfaces; but as we proceed northward, and reach the harder Magnesian and Carboniferous Limestones of Durham and Northumberland, we find the Boulder-clay resting upon smooth and polished surfaces of these rocks.

Nevertheless, although there is an absence of striated and polished surfaces in the Eastern Counties, other phenomena are almost equally conclusive of land-glaciation. In passing from the south to the north, the *white* chalk, the *dark grey* Kimmeridge and Oxford clays, the *light yellow* Oolitic strata, the *grey* Lias, the *red* Sandstones and Marls, and *black* beds of the Carboniferous rocks, come successively to the surface; and it is found that the Boulder-clay not only partakes in each area of the nature and colour of the underlying rocks, which the ice has ploughed up, but also maintains the colour, and is composed largely of the débris (clay and gravel), of the rocks which it successively overlaps, for a considerable distance to the south of their outcrop; whereas on the north side there is an entire absence of such débris,—thus showing a north to south course of the ice-sheet as represented in the following diagram :—

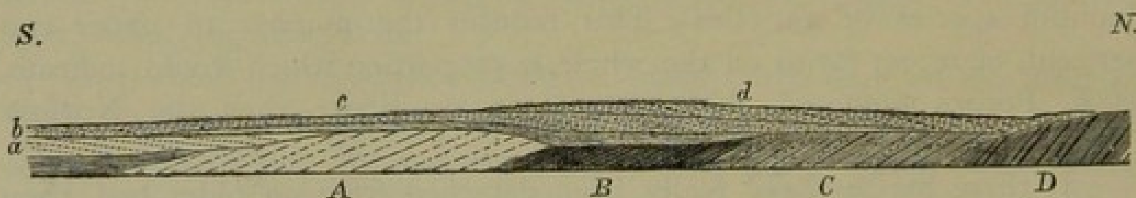

FIG. 214. Theoretical diagram of the successive overlaps of the Boulder series over different strata, on the north-east coast.

A. Chalk. B. Jurassic strata. C. Triassic strata. D. Carboniferous strata. a. Chalky Boulder-clay. b. Grey Boulder-clay. c. Red Boulder-clay. d. Grey and carbonaceous Boulder-clay.

Another ingenious proof of direct land-glaciation has been adduced by Mr. Skertchly. He notices that in Oolitic districts, where beds of clay alternate with limestones, the Boulder-clay is often found on the clays, but not on the limestones. He explains this by the circumstance that the clays (on the sides of pre-glacial valleys) have yielded to the pressure of the ice-plough to a greater extent than the limestones, and in the depressions so formed the Boulder-clay has lodged. At the subsequent denudation of the district these lodgments of Boulder-clay, protected by the projecting limestones, have escaped the denudation which has swept it away in the other parts.

The Glacial Series of the West of England. There is little Drift on the high land of Central England, but in the lower lands on the Western side we again find a thick covering of deposits belonging

[1] 'Quart. Journ. Geol. Soc.' vol. xvii. p. 46.

to the Glacial Series. In Shropshire, Cheshire, and Lancashire these have a general triple division, similar to that of the Eastern Counties. The Lower Boulder-clay is divisible into an unfossiliferous basement Till, and an upper shelly clay, in which a few arctic species of shells, such as *Leda pernula*, *Astarte compressa*, *Saxicava rugosa*, *Natica affinis*, occur. The surface of the rocks beneath the Till is often finely glaciated; at times this may even be seen in parts of Liverpool.

To these succeed roughly stratified sands and gravel, with boulders similar to those in the underlying clay and shells of contemporaneous age usually broken and worn. The number of species in these beds is generally greater than in the clays, and they are less arctic in their character. Of the fifty species enumerated by Mr. De Rance, thirty-eight occur in the Red and Norwich Crags, forty are northern and thirty-two southern forms, and twenty-nine are still living on the Lancashire sea-coast[1]. Amongst the more common species occurring in these inter-glacial beds are,—

Ostrea edulis, *Linn.*
Pecten opercularis, *Linn.*
Mytilus edulis, *Linn.*
Cardium edule, *Linn.*
Cyprina Islandica, *Linn.*
Tellina Balthica, *Linn.* Fig. 215, *b*.
Astarte borealis, *Chemn.* Pl. XVI, fig. 5.
Psammobia Ferroensis, *Chemn.*
Trophon truncatum, *Ström.*
Littorina littorea, *Linn.*
Turritella terebra, *Sby.* (communis, *L.*) Fig. 215, *a*.
Purpura lapillus, *Linn.*
Buccinum undatum, *Linn.*
Murex erinaceus, *Linn.*
Fusus antiquus, *Linn.* (T. antiquum). Fig. 210, *h*.
Nassa reticulata, *Linn.*

The Lower Boulder-clay does not extend to heights exceeding 200 to 300 feet, whereas the overlying sands and gravel are not only spread out on the low lands, and to the sea-level on the coast at Blackpool, but they also occur in patches on higher ground, as on the hills between Macclesfield and Buxton, at a height of 1150 feet, and on Moel Tryfaen in North Wales, at 1360 feet. At the latter place the shell-bed is covered by an Upper Boulder-clay.

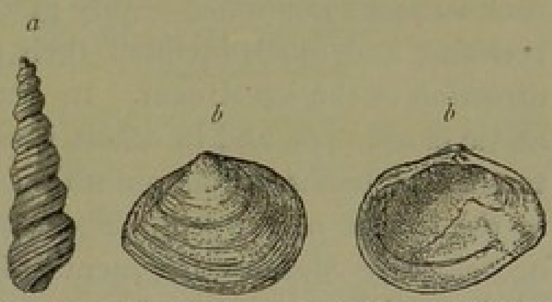

FIG. 215. *a. Turritella communis*, Risso. *b. Tellina Balthica*, Linn.

Mr. Darbishire[2] gives a list of fifty-six species from this locality. They are of the same species as those in the Lancashire boulder-sands, with the addition of *Astarte compressa* and *A. sulcata*; while *Psammobia* is absent. But the greater number are rare.

[1] See Mr. De Rance's paper 'On the Superficial Geology of Lancashire,' etc., 'Mem. Geol. Survey,' 1877; also the various papers of Messrs. R. D. Darbishire, Mellard Reade, G. H. Morton, Mackintosh, Prof. Hull, and others, in 'Proc. Lit. and Phil. Soc. Manchest.,' 'Proc. Manch. and Liverpool Geol. Soc.,' 'Geol. Mag.,' and 'Quart. Journ. Geol. Soc.'

[2] 'Geol. Mag.,' vol. ii. p. 298, 1865, 'Quart. Journ. Geol. Soc.,' vol. xxx. p. 38; also Ramsay's 'Physical Geography and Geology of Great Britain,' 5th edit., pp. 414-416.

The Upper Boulder-clay, like the associated sands and gravels, usually only extends from the sea-level to heights from 500 to 600 feet, but it runs up higher into some of the pre-glacial valleys and over some hills. Like the Lower Boulder-clay, it consists of a dark-coloured unstratified clay, with fragments and blocks of rock of all sizes irregularly dispersed through its mass in more or less abundance. The great bulk of the stones are foreign to the district, are more or less angular or worn, often striated by ice-action, and lie at all angles. Out of 100 stones taken from the Boulder-clay at Manchester, where it overlies Permian strata, Mr. E. W. Binney found—

Granites, greenstones, porphyries, etc.	42	From Cumberland, Westmoreland, and Scotland.
Slates and Silurian rocks	44	
Carboniferous limestone	4	From North Lancashire.
Coal-measure sandstones	8	
New-red-sandstones (or Permian)	2	Local.

In the western parts of Lancashire Mr. De Rance found 28 per cent. of the Lake-district volcanic rocks, and 20 of granite. In each case there is evidence of a transport from the more northern counties or from Scotland. Boulders of Shap granite are met with as far south as Cheshire. Fifteen shells—all with one exception of the same species as in the underlying sands and gravel—are recorded from these upper beds. They are mostly in fragments, and worn.

In Scotland the basement Till, which is considered by the Scotch geologists to have originated under a glacier (*moraine profonde*), overlies rock-surfaces sometimes highly glaciated; at other times, where they are less resisting and much inclined, their edges are broken and turned back in the direction of the ice-stream. In places the Till overlies shell-beds of highly arctic characters, and in others it envelopes débris (remains of plants, a few teeth and bones of mammoth) of a land-surface. The shell-beds extend to the height of 510 feet. The Till which, though generally unfossiliferous, occasionally contains fragments of shells, attains a thickness of about 100 feet or rather more.

To this succeed clays interstratified with boulder-sands and gravels; morainic débris, and erratic blocks; while, up the Valley of the Clyde, and in some of the valleys on the east coast, come the later brick-earths, with their arctic molluscan fauna, mixed, however, with a considerable number of species still living in the Scottish seas[1]. Amongst the most characteristic of these shells are,—

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[1] See Mr. J. Smith's (of Jordanhill) 'Newer Pliocene Geology;' Dr. A. Geikie's 'The Glacial Drift of Scotland;' Dr. Crosskey's and Mr. Robertson's 'Post-Tertiary Fossiliferous Beds of Scotland;' 'Trans. Glasgow Geol. Soc.,' vol. ii. p. 267, vol. iii. and iv (several papers); Dr. J. Geikie's 'The Great Ice Age;' Mr. Ralph Richardson in 'Trans. Geol. Soc. Edinb.,' vol. iv. p. 179; and papers by the Rev. J. Brown in 'Trans. Roy. Soc. Edinb.,' 1862–67.

Pecten Islandicus, *Müll.* Pl. XVI, fig. 4.
Panopæa arctica, *Gould.* Pl. XVI, fig. 1.
Mya truncata, *Linn.* Pl. XVI, fig. 2.
Leda pernula, *Müll.* Pl. XVI, fig. 8.
Astarte borealis, *Chemn.* Pl. XVI, fig. 5.
Saxicava rugosa, *Linn.* Pl. XVI, fig. 3.
Tellina calcarea, *Chemn.* Pl. XVI, fig. 6.
Cardium Norvegicum, *Speng.*
Trophon clathratum, *Linn.* Pl. XVI, fig. 10.
Scalaria Grœnlandica, *Chemn.*
Buccinum Grœnlandicum, *Chemn.*
Littorina limata, *Lov.* Pl. XVI, fig. 12.
Pleurotoma turricula, *Mont.*
Trochus Grœnlandicus, *Chemn.*
Velutina lævigata, *Penn.* Pl. XVI, fig. 9.
Lacuna divaricata, *Fabr.*

Erratic Blocks[1]. An important feature to notice in connection with the Glacial Series is the wide dispersion of erratic blocks at all levels up to heights of 3000 feet. Some of these may be remnants left on removal of the Boulder-clay; a larger number may have been left where they now stand on the melting of the great ice-sheet on which they travelled; or some may have been transported to their present positions by floating ice-rafts.

In Scotland erratic blocks have travelled 80 to 100 miles southward from their parent rock; and Dr. J. Geikie remarks that they have usually followed the direction of the ice-striæ, and have therefore, like the ice-currents themselves, been deflected in their course by the deeper valleys and higher hills. The hills of Carboniferous Limestone around Clapham and Settle are strewn with boulders of the Silurian slates, which crop out several miles to the north. In this case the glaciated limestone where not protected by the blocks, having been slowly dissolved away by the rain, has left the blocks perched on pedestals from one to three feet high, as represented in the above figure.

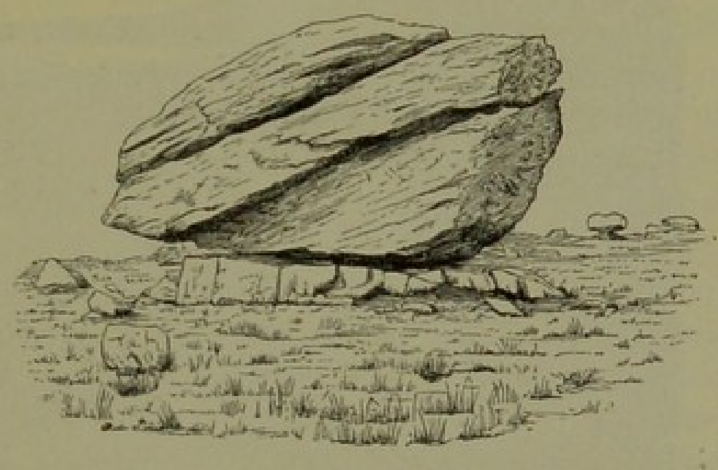

FIG. 216. *Boulder* (5′.8″×9′.8′) *of coarse Silurian slate on the hills of Carboniferous Limestone above Clapham in Yorkshire. The platform on which it rests now rises about* 1 *foot above the general level of the surface.* (From a photograph by Mr. Tiddeman.)

Granite boulders from Criffel in Galloway, as well as from Eskdale in Cumberland, are scattered over the plains and high on the hills of Cheshire, and across the plains of Shropshire as far as Wolverhampton and Bridgenorth. The boulders of northern granite do not pass beyond Bridgenorth. Further south the erratic blocks of the Severn Valley and of Worcestershire consist of felsites, porphyries, and slates, derived from the mountains of Wales, which formed another centre of dispersion.

[1] The reader should consult the valuable reports of the Boulder Committee of the Royal Society of Edinburgh, 1872, *et seq.*; the many papers by Mr. D. Mackintosh on the distribution of Boulders, in 'Quart. Journ. Geol. Soc.' and 'Geol. Mag.;' and the 'Reports on Erratic Blocks of Great Britain and Ireland,' in Reports, Brit. Assoc., 1873–1886.

Those from the Arenig hills are of a very marked character. The hills of Charnwood Forest formed another centre; blocks of rocks from that source have travelled thirty miles southward, while others have been found fifty miles to the south-west in North Shropshire.

Nowhere else in Europe is there so complete a series of glacial deposits as those just noticed. They afford evidence of the effects of the extreme cold on the fauna and flora, and are standing proofs of the physiographical changes which took place in Great Britain during the Glacial period. They point at its inset to a boreal condition of the surrounding seas, and a severe climate on land, followed by the gradual creeping over the land of a vast ice-sheet. As this moved forward it rasped and planed down the asperities of the rocks over which it passed, leaving their surface smooth or polished, and covered with parallel rectilinear striæ and grooves like those on the rock-floors of the glaciers in present Alpine regions.

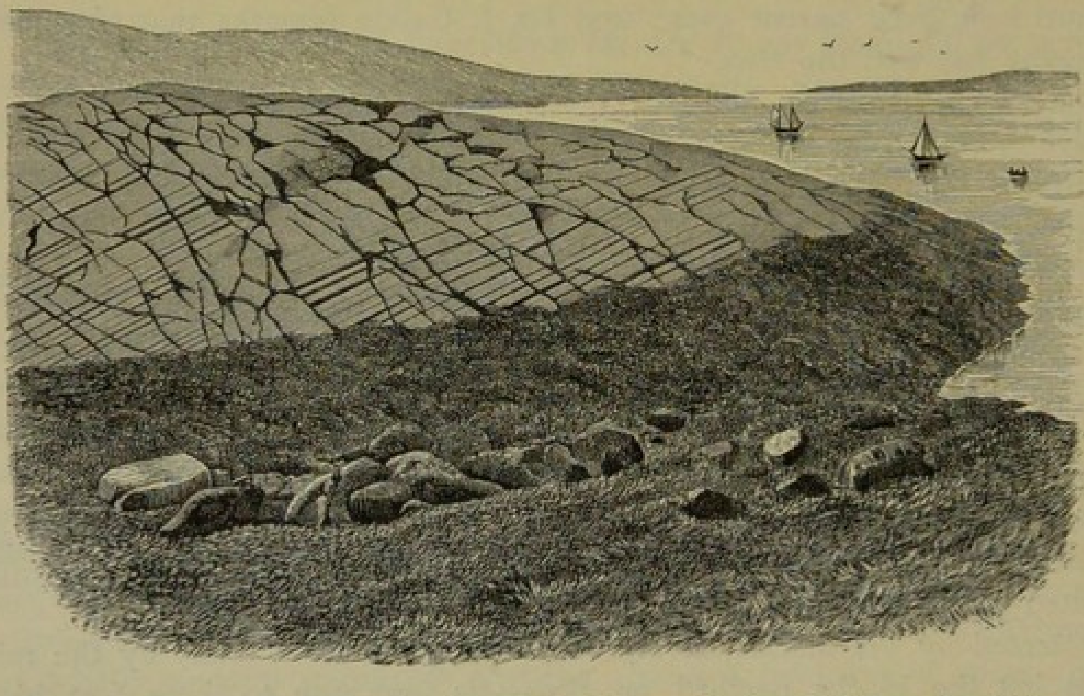

FIG. 217. *View of the glaciated surface of the Island of Eilean-an-Lonain on Loch Sween, Argyllshire.* (From a Photograph.)

Amongst the many fine examples of this action in Scotland, where its traces may be observed up to heights of 3500 feet, probably one of the most wonderful is shown in the island of Eilean-an-Lonain on the coast of Argyllshire, for the view of which I am indebted to Dr. H. W. Crosskey.

In this case the top of a low hill has been worn down until reduced to the smooth rounded stump it now presents, which resembles, though on a larger scale, the smaller well-known 'roches moutonnées' of all glaciated lands. Generally, such surfaces are covered by surface-soil and grass, or by the Till or Boulder-clay; but in this instance the surface is bare, just as it was left on the melting off of the ice-cap long years ago. The rock is a crystalline schist, and the striation runs E.N.E. and W.S.W.

Equally marvellous is the glaciation of the Northern Counties of England. There also only a few of the higher hills escaped the grasp of the great ice-sheet, the marks of which are perceptible up to heights of about 2500 feet in the Lake district[1]. As the land-ice travelled southward it became thinner, and its traces are gradually lost. The Glacial drift-beds die out on the hills immediately north of London; whence their boundary passes by Oxford to South Wales. In Wales it is prolonged to the south-western extremity of Pembrokeshire, and it is possible that the Sole Bank[2] in lat. 49° N. and long. 10° W., with its angular granitic débris, may mark the limit of the great glaciers, which, descending from the higher grounds of Great Britain and Ireland, became confluent in the Irish Channel. The associated glaciers possibly formed at that extreme point a vast frontage to the sea like some of the great glaciers of North Greenland at the present day; for the late Mr. Godwin-Austen showed that an old coast-line, now submerged, once probably extended from the French to the Irish coast[3].

Although the ice-sheet passed in a general direction southward entirely over some hills, or through the 'cols,' and over the shoulders of the higher ranges, it did so just as a river in flood would do, that is to say, at first following the general direction of the valleys, and, when the ice overflowed them, passing straight on over the higher ground, independently of the minor irregularities of the surface. Consequently, the striæ present a system of extreme complexity. They follow valleys, they wind round hills, and pass over the tops of hills. The conclusion with respect to Scotland is, that though there was a general movement of a large body of ice from the higher grounds of the north to the lower lands of the south, there was at the same time a flow from certain high centres of dispersion eastward through the great friths, and westward through the sea lochs and fiords; while in the extreme north of Scotland the ice also had an outward or northward movement.

In the north of England, the high lands of Westmoreland and Cumberland formed another centre of dispersion, subject however to the influence of the great mass of ice from Scotland. The general southern direction was also more maintained, because of the large body of ice passing down the St. George's Channel, which acted as a retaining wall, and forced the ice of the Northern Counties to pass either southward or eastward. The phenomena, as a whole, go to show that the glaciation of Great Britain was not due to a great polar ice-cap, but was of local and independent origin.

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[1] Tiddeman, 'Quart. Journ. Geol. Soc.,' vol. xxviii. p. 471; and Ward, vols. xxix, xxx, xxxi.

[2] 'Phil. Trans.' for 1879, p. 61.

[3] 'Quart. Journ. Geol. Soc.,' vol. vi. p. 69.

To resume, it would seem on the evidence we have before us, that after the first extreme glaciation, and the formation of the Lower Boulder-clay or Till, a great depression ensued, by which Central England, Wales and Ireland, were submerged to the extent of 1500 to 2000 feet. This led apparently for a time to the inset of warm marine currents, and the introduction of a more southern marine fauna; but, as the land again rose, and the warmer currents were diverted or stayed, colder conditions resumed, and arctic mollusca returned for a time to the coasts of Scotland.

With the passing away of the more extreme glacial conditions, and the gradual amelioration of climate, the ice-sheet melted from off all the lower levels, until only the higher mountains of Wales and Scotland retained their capping of permanent snow and ice. Then, instead of the general southward movement of the great body of ice, irrespective of the

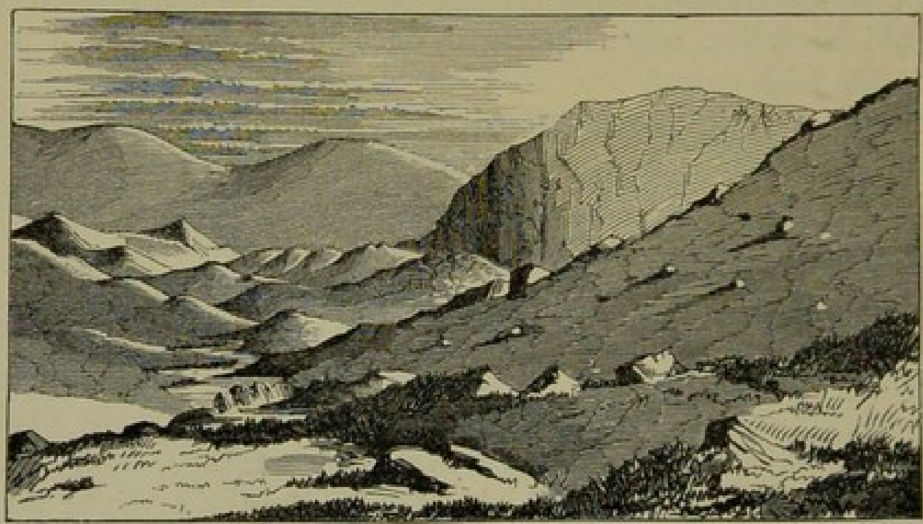

FIG. 218. *View of the moraine-hillocks in the Upper Talla Valley, Peeblesshire.* (Dr. A. Geikie.)

minor irregularities of the surface, a new glacier-system, analogous to that of Alpine regions at the present time, set in. The ice-streams, now restricted to the deeper and higher valleys of the mountain-centres, descended in *radiating* courses to the warmer plains at their base, and there discharged their terminal moraines. Of this last and lesser ice-system Ramsay gives some illustrative examples in the Snowdon district. The above figure is a good illustration of the smaller moraines due to these local glaciers in Scotland.

With the change in climate the fauna and flora returned by degrees to the lands now released from the long ice-grip; and, although the temperature still continued lower, and river-action more powerful in these latitudes than at the present day, the present drainage-areas were established and early *Man* appeared or returned definitely on the scene.

CHAPTER XXIX.

THE GLACIAL DEPOSITS OF EUROPE AND OTHER PARTS OF THE WORLD.

SCANDINAVIA. EXTENT AND DIRECTION OF THE ICE-FLOW. ELEVATION AND SUBMERGENCE. SEA-MARGINS. UDDEVALLA. SHELL-BANKS. NORTH GERMANY: SCANDINAVIAN BOULDERS, AND MARINE SHELLS. OTHER CENTRES OF GLACIERS IN EUROPE. FRANCE. ITALY. SPAIN. THE ALPS. GREAT LENGTH OF THE OLD GLACIERS. THICKNESS OF THE ICE. MAGNITUDE OF THE OLD MORAINES IN THE PLAINS OF LOMBARDY. INTER-GLACIAL BEDS: NOT INDICATIVE OF A RADICAL CHANGE. DUE ONLY TO MINOR TEMPORARY CAUSES. DÜRNTEN. NORTHERN ASIA. FROZEN GROUND. MAMMOTH REMAINS. IVORY. SMALL HAIRY ELEPHANT. OTHER PARTS OF ASIA AND INDIA. THE CAUCASUS. THE HIMALAYAS. NORTH AFRICA. THE ATLAS MOUNTAINS. NORTH AMERICA. GREENLAND. THE MAINLAND. ESCHOLTZ BAY. FROZEN CLIFF. ALASKA. BRITISH COLUMBIA. BOULDER-CLAYS. NICARAGUA. GLACIAL ACTION IN THE SOUTHERN HEMISPHERE. CHILI. PATAGONIA. SOUTH AFRICA. AUSTRALIA. NEW ZEALAND.

Scandinavia. In North-western Europe the evidence of the prevalence of a Glacial Period is similar to that which we have in Britain. It shows that the mountains of Scandinavia were covered by a great ice-sheet, one portion of which flowed westward into the North Atlantic, while other portions passed northward into the Polar Sea, eastward over Finland, and southward over Sweden and the islands of the Baltic. Throughout this area the rocks are glaciated and covered in places with a tenacious boulder-clay full of striated stones and boulders. This clay extends as far as the coast of Germany, where it is replaced by a thick accumulation of sand and gravel, with large boulders, which lie scattered from Tcheskaia Bay to a point a few miles south of Moscow and Warsaw, and thence by Leipsic and Hanover to the coast of Holland. It is supposed by some geologists that the ice-sheet itself extended as far as the boulders reached, from the circumstance that in the neighbourhood of Leipsic, not only does the Boulder-clay contain blocks of well-known Scandinavian rocks, but some of the rock-surfaces are also glaciated. This glaciation, however, may be due to local glaciers that descended from the Erzgebirge, the Hartz, and other mountains of Central Germany, while the stones and boulders may have been carried by floating ice from the Scandinavian glaciers, just as we have Scandinavian rocks in the lower marine boulder-clay of Norfolk[1].

[1] For Europe in general the reader should consult Dr. J. Geikie's 'Prehistoric Europe.'

After the first excessive glaciation, the Scandinavian range—which then, judging from the depth of the ice-worn fiords on its eastern coast, stood considerably higher than it does now—was submerged to the extent of about 1000 feet beneath the present sea-level. Gravel and shingle terraces, occasionally with shells, mark the levels at which the sea has successively stood as the land rose to its present height. The shells, however, have not been found at levels higher than about 600 feet. In places they occur in extraordinary abundance, as on a hill near Uddevalla in South Sweden, where they form a large loose shell-bank that has been quarried for years. The species are numerous and mostly the same as those which are found in the inter-glacial sands and gravels of Lancashire; the most common shells are *Astarte borealis*, *Panopæa Norvegica*, *Mya truncata*, *Saxicava rugosa*, *Littorina rudis*, *Natica clausa*, *Buccinum Grœnlandicum*, etc. The profusion of these shells and the presence of Balani, etc., attached to the rocks, show that the sea rested at this level, 200 feet above the North Sea, for a considerable time.

Germany. During this partial submergence of Norway and Sweden the sea spread over a large tract of land in North Germany and adjacent districts; and across this sea the bergs and shore-ice of the Scandinavian coast floated masses of *débris* and boulders.

Huge blocks of Finnish granite are scattered over the plains of St. Petersburg, and extend to the neighbourhood of Moscow. In Poland and North-Eastern Germany, boulders from the rocks of Finland are mingled with others from North Sweden; while throughout North-Western Germany, Hanover, and as far as Holland, the boulders consist of gneiss, granite, diorite, and Silurian rocks from the southern parts of Sweden. The marine shells found in this boulder series are generally limited to a few specimens of *Cardium edule* and *Nassa reticulata*, except in the neighbourhood of Bromberg and Thorn in North-West Prussia, where *Cyprina Islandica*, *Ostrea edulis*, *Mactra subtruncata*, *Tellina Balthica*, etc., have also been found.

During the Glacial Epoch all the chief mountain-chains of Europe likewise had their glaciers. In France they existed on the higher hills of Auvergne, of the Morvan, the Cevennes, the Vosges, and the Pyrenees. In Spain, on the Sierra Nevada, the mountains of Estremadura, and elsewhere. In Germany and Hungary, on the mountains of the Black Forest, the Hartz, the Erzgebirge, and the Carpathians. In Italy, on the Apennines.

The Alps were the centre of a gigantic system of glaciers, which have been admirably mapped and described by the Swiss geologists[1]. The

[1] See A. Favre, 'Géologie de la Savoie,' vol. iv. chaps. iv–x, 1867, and his valuable 'Cartes des Anciens Glaciers de la Suisse,' 1884; also Falsan and Chantre in 'Bull. Soc. Géol. France,' 2e sér. vol. xxvi. p. 360.

glaciers of Mount Blanc, which are now stayed above Chamouni, then flowed down the valley of the Arve to Geneva, where the ice-stream became confluent with one branch of the great glacier of the Rhone, and descended with it to the neighbourhood of Lyons and Vienne, forming a continuous ice-stream 240 to 250 miles in length, and with a frontage of 40 to 50 miles. Perched high on the precipitous brow of Mount Salève, overlooking the plain of Geneva, great boulders of the rocks of Mount Blanc remain as monuments of this ice-deluge; while blocks of these and other Alpine rocks are scattered at various elevations as far as Lyons.

Another branch of the great Rhone glacier, after passing by Lausanne, abutted against the flanks of the Jura, which it strewed with blocks from the Central Alps. This ice-stream then passed north-eastward, filling the Lake of Neufchâtel, and became confluent with other glaciers descending from the valley of the Aar and from the valleys above Lucerne. A remarkable exhibition of a glaciated surface, and of the huge pot-holes formed during the occupation of the ice, is now exposed at Lucerne.

Another large stream descended the valley of the Rhine, and, coalescing with the one just named, the combined streams poured down the Rhine valley to the neighbourhood of Thiengen, below Schaffhausen; while another great mass passed eastward into the valley of the Danube, which it descended to near Ulm.

The transported blocks are all more or less angular, and are sometimes of colossal dimensions. A block of granite carried on the ice from the Valais to the vicinity of Soleure, a distance of 115 miles, weighs about 4100 tons. The celebrated Pierre-à-Bot, above Neufchâtel, measures 50′ × 20′ × 40′, and contains about 40,000 cubic feet of stone; while the Pierre-des-Marmettes, near Monthey, contains no less than 60,840 cubic feet. (For a modern illustration of transport by ice see Vol I, fig. 65.)

Thus all the now fair land of Switzerland was buried under a vast accumulation of ice, which, in the plain between the Alps and the Jura, is estimated to have been not less than 3000 feet thick; for on the latter range it has left its marks up to a height of 2000 feet above the Lake of Neufchâtel. If this long plain could be now bared of its surface-soil, it would be found overspread with old moraine *débris* of clay, sand, and gravel, and of boulders carried down with the ice from the Central Alpine ridges—the result of the wide-spread action of this former great ice-sheet.

Italy. On the Italian side of the Alps all the deep valleys and lake-basins were in like manner filled to the height of 2000 to 3000 feet by glaciers, which, when they emerged from the narrow limits of the valley, spread out fan-shaped in the great plains of Lombardy, where they have left moraines, both lateral and terminal, which testify to the magnitude of the ice-streams. But whereas, owing to the barrier formed by the range of the Jura, and to the more limited area of the plains, the Swiss glaciers, in issuing from the Alps, became confluent, and their moraines intermingled or levelled, the Italian glaciers, meeting with no obstruction, projected into the broad valley of the Po, each as a separate stream. Consequently, their moraines form trenchant and detached ridges. The terminal moraines form conspicuous and semicircular ranges of hills, from 300 to 1000 feet in height, some miles in front of and parallel with the Alpine range. The greatest of these ice-streams—that descending from the valley of Aosta—had a total length of 120 miles. That which came down from the Eastern Alps to the neighbourhood of Verona formed the well-known heights of Lonato and Solferino, which rise some 500 to 700 feet above the surrounding plains.

Inside these great terminal moraines, and separated from them by narrower valleys, are a number of lesser parallel ridges marking the several points of temporary rest during the retreat of the glaciers. These are further flanked by lateral moraines, some of which are of vast size. M. Favre mentions the one on the left bank of the Doire, which extends for a distance of 21 miles, and rises to a height of 2000 feet above the level of the river, as being probably the greatest known of these old moraines.

Interglacial Beds. A question which of late years has attracted much attention is whether or not the old Alpine glaciers show that there were two or more epochs of extreme cold, separated by one or more warm independent Interglacial epochs;—these alternations being of long duration and not due, as now, to ordinary short climatal vicissitudes, but to some cosmical (or whatever other) cause, such as that which originated the Glacial epoch itself.

Thus in the opinion of some eminent geologists, there was a first great retreat of the glaciers, but possibly not to their present circumscribed area. The country then again became inhabited by a number of large animals, and forested with Pines, Firs, Birch, and a few Oaks, after which time the climate again became so severe as to lead to the return of the ice over its old ground. Amongst the localities cited in support of this view are Dürnten and Utznach, near Zurich, where beds with lignite and mammalian remains are intercalated between two glacial deposits.

Admitting the fact that the Dürnten lignites rest on beds of undoubted glacial (ground-moraine) origin, and that the trees grew on the spot where their stumps and remains are found, it by no means follows, as contended, that because these trees are all of species now living in Switzerland that the temperature was as high as that of Switzerland at the present day. The *Pinus sylvestris*, *Abies excelsa*, the Yew, the Birch, and the Oak, flourish equally in Sweden and far north in Siberia: and there is an absence in the scanty Dürnten flora of those plants which, while having a more southern range, also now live in Switzerland. On the other hand, there is there one species of *Pinus* (*P. montana*) which is spread over the mountain country up to heights of 7000 feet, and is rare in the low lands: while one of the mosses in the lignite is closely allied to a species now growing on the hills of Lapland. The few species of Mammalia have a distinctly northern facies. The *Elephas primigenius*, *E. antiquus*, the *Ursus spelæus*, and even the *Cervus elaphus* and *Bos primigenius*, are commonly associated with Reindeer, Musk-ox, and other Arctic animals of cold Post-glacial times. Further, both the trees and animals are those of our 'Forest-bed,' the last land-survival before the climax of the Glacial Period.

Is the return, therefore, of the retreating glacier,—supposing the Boulder-gravel above the lignites of Dürnten to be due to direct ice-action,—to be ascribed to anything more than a comparatively slight temporary change of climate, like those, only more marked, that now for a succession of seasons cause, from time to time, a temporary advance of the glaciers? We must allow, of course, for greater differences, and possibly longer intervals of time than now obtain.

Such minor vicissitudes of climate seem more compatible with changes in the physiography of Europe than with the cosmical causes to which the Glacial Epoch, as a whole, was, there can be little doubt, due. Nor is it difficult to find such a cause in the extensive changes in the distribution of land and water which took place in Britain and Northern Europe after the first great land-glaciation and the formation of the Lower Boulder-clay. The submergence of Ireland, Wales, Scotland, and England (in part), and of a still larger area in Russia and North Germany, extending to Holland [1], was sufficient, with the influence of currents from the south (for in the shells of the Middle Boulder-series there is a large per-centage of southern forms and an absence of extreme arctic forms), to effect a considerable amelioration of the climate, such as would lead, for a time, to the return of the old Pre-glacial fauna aud flora.

With the rise of the temporarily-submerged lands the climate again changed, and brought the Alpine glaciers back over part of their former ground, overwhelming in their course the forest-growth which had sprung up in the meantime,—a growth which might be the work of no very long period; it is well known also how close vegetation can keep to the confines of glacier-ice.

Besides the question of an *interglacial period*, which in the sense intended by the authors I am unable to accept, there is another point of special interest, relating to the antiquity of Man, connected with these lignites. A few years ago there were found in the lignite of Wetzikon [2] some thin boughs of fir (*Abies excelsa?*) lying side by side, and with the

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[1] Possibly also of parts of Southern Europe and North Africa.

[2] Heer's 'Switzerland,' English edit., chap. xii and Appendix I.

ends said to be cut to a point. From this circumstance and from their having apparently been tied together, they were supposed by some to have been part of a basket or wattle-work made by early man. This conclusion is contested, however, as the wood is much crushed, and the work, if any, very obscure.

In Northern Asia, after passing the Urals, there is no evidence of land-glaciation, although there is evidence of extreme cold. Then, as now, owing to the dryness of the climate, no great glaciers appear to have existed, nevertheless the land is still frozen to the depth of more than 200 feet at Yakutsk, in lat. 62° N.; and at the mouth and in the deltas of many of the Siberian rivers the frozen ground and ice form cliffs in which are preserved the bones and even the undecomposed carcases of the Mammoth and Woolly Rhinoceros. Herds of these animals seem to have been destroyed in early Quaternary times. Swept down by the river-floods and entombed in the ever-increasing annual ice-growth of the Glacial Period, there they have remained for untold ages, until now released, from time to time, by the wearing away of the river banks, or by summer thaws.

In 1799 a Tungusian chief observed the obscure form of a Mammoth in the face of a frozen cliff at the mouth of the Lena. The body was firmly fixed in the ice, and it was five years before it fell out[1]. It was still so fresh that the flesh was devoured by dogs, wolves, and bears, but the skeleton and parts of the skin, which was covered with a light-coloured curly, very thick-set hair one to two inches in length, interspersed with darker-coloured hair and bristles from four to eighteen inches long, were fortunately rescued in time, and are preserved in the Museum at St. Petersburg[2].

Several such discoveries have been made, as well of the Mammoth as of the Woolly Rhinoceros (*R. tichorhinus*); and in one of the latter instances some of the food of the animal was found in the cavities of the teeth. A microscopic examination showed that these great extinct animals fed on the leaves and shoots of the coniferous trees which then clothed the plains of Siberia. Their remains are found, however, not only on the river-banks, but also on the islands off the coast, even as far north as the newly-discovered Bennett's Island in 76° lat. The heads and tusks often so abound, and the latter are in such a perfect state of preservation, that for long they supplied Russia with all its ivory, and considerable quantities of the tusks have been, from time to time, imported into London. Richardson mentions that, in 1821, 20,000 pounds of ivory, some of the tusks being of great size, were obtained from the islands of New Siberia. In 1872 and 1873 as many as 2770 Mammoth tusks, weighing from 140 to 160 pounds each, were entered at the London Docks.

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[1] Dr. Tilesius, 'Mem. Imp. Acad. Sci. of St. Petersburg,' vol. v.

[2] Some of the soft parts attached to the skin still admitted of microscopic examination. One of the eyes even was preserved. The remains were not rescued until June 1806.

The now barren plains of Siberia seem to have been the centre from which these animals, whose remains are found all over temperate and northern Europe, spread. The Elephant, like the Tiger, can even now live in regions of considerable winter cold. Bishop Heber mentions[1] that when travelling in Nepaul, among the lower ranges of the Himalayas, and at an elevation of 5000 to 6000 feet, he was on one occasion accompanied by the Rajah who was seated on a little female elephant *hardly bigger than the Durham ox, and about as shaggy as a poodle*. She was a native of the neighbouring woods, where the elephants were said generally, though not always, to be of smaller size than those of Bengal. The cold in this district was such that it froze in the shade in November. The tiger also goes up to the adjacent glaciers.

Other parts of Asia and India. The glaciers of the high range of the Caucasus had formerly a far greater extension: and Sir Joseph Hooker discovered that in the range of the Lebanon the remains of old moraines are still conspicuous. In Northern India he found traces of glaciation in the valleys of Sikkim and Eastern Nepaul down to levels of 5000 feet, or about 6000 feet below the level of the existing glaciers. In the Western Himalayas, perched blocks are found at still lower heights. Dr. Blanford also states that the hills of Southern India, although exhibiting no signs of glacial action, afford, in the character of some of the animals and plants now inhabiting them, evidence that a lower temperature probably prevailed in Peninsular India at a comparatively recent geological period[2]. In Central Asia, in Persia, in China, and Kamtchatka, the higher ranges of mountains afford undoubted evidences of glacial action. But of glacial deposits, as ordinarily understood in this part of the world, we know little or nothing. We know only that large tracts in China are covered by thick deposits of Loess. It has, however, been questioned whether the origin of this Loess is the same as that ascribed to it in Europe.

North Africa. The snow-capped range of the Great Atlas attains a height of from 12,000 to 13,000 feet[3]. No glaciers now exist there. Mr. Maw states, however, that perhaps the most remarkable feature in the physical geology of Morocco is the enormous deposits of boulders that occur in the lateral valleys, and flank the great chain of the Atlas on its confines with the plain. The summits of some of these mounds were found to be 3950 feet above the sea-level, and they spread down interruptedly to the edge of the plain nearly 2000 feet below. Kindred phenomena occur higher up in the Atlas valleys. But the most notable case of unquestionable moraines seen by his party was at an altitude of

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[1] 'Heber's Journal,' vol. i. p. 461.
[2] 'Manual of the Geology of India,' p. 373.
[3] 'Morocco and its Great Atlas,' pp. 199, 458.

6000 feet. They there met with a gigantic ridge, which had a vertical height of 800 to 900 feet, and was composed of great masses of rock (mostly blocks of porphyry) that dammed up the steep ravine and had led to the formation of a small alluvial plain above it.

North America. The north-east of America presents, like the north-west of Europe, a large area exhibiting extreme glacial action; but in the absence of Pliocene strata the transition from the ante-glacial to the glacial deposits, which constitutes so important a link in the chain in this and some other parts of Europe, is wanting. In America the ice advanced over lands that had long before emerged, and consisted almost entirely of Archæan and Palæozoic rocks that had for ages existed as dry land. From the shores of the Arctic Ocean to lat. 41° and 37° N., and from the Atlantic border to long. 100° W., the whole vast tract exhibits the ice-scratched and glaciated rocks *in sitû*, covered by transported boulders, sands, and gravel, due to the effects of prolonged ice-action.

Some geologists are of opinion that Greenland was the centre of dispersion of the American ice-sheet, as Scandinavia was of that of the North-European area. But as in North-western Europe there were at the same time independent centres of dispersion in Great Britain and Ireland and in continental Europe, so in America it is probable, as held by other geologists, that the highlands of Canada and mountain-ranges of the United States there formed other independent centres; while it is doubtful whether in America, any more than in Europe, the ice-sheet was connected with a great polar ice-cap. In Scandinavia the quaquaversal direction of the ice-striæ—and in Scotland the same fact seems to be recognised—is incompatible with polar ice-cap; nor is the evidence in America sufficient to support that view. In the vast tracts of land north of Hudson's Bay and the great lakes scarcely anything is, however, known of the direction of the ice-striæ.

In Greenland in Glacial times the large volume of ice of the central plateau appears to have passed out, as it does now, through the deep fiords of the west coast-range. An island in front of one of these fiords bears transported blocks on its summit which is 1800 feet high, while the sides of the fiords show traces of ice-action to still greater heights above the sea-level. The depth of the fiords (1100 to 1200 feet) also indicates that then the land, and consequently the sea-bed, probably stood higher than now. But whether even then the ice could have passed across such a channel as that of Davis' Strait and Baffin's Bay,—the depth of which reaches from 5000 to 6000 feet[1],—and extend thence over the American mainland, seems very problematical. It is equally or more probable that the ice of

[1] The depth of the German Ocean does not exceed 300 to 400 feet, except in a narrow belt along the coast of Norway, which has a depth of 2600 feet.

Greenland, together with that of the American mainland, met in, and escaped southward through, Baffin's Bay into the Atlantic ocean.

The American geologists are of opinion that at the commencement of the Glacial Period, the highlands of Canada stood 1000 to 2000 feet higher than at present, and that it was on those highlands that the main mass of the great ice-sheet had its source. It then passed across the valley of the St. Lawrence, over the mountains of the northern States, and descended into the lower lands southwards as far as the States of New York, Ohio, and Illinois, and south-westward across the valley of the Mississippi to Dakota. The ice-sheet does not appear to have extended as far as the Rocky Mountains; but its limit on its western edge northward to the Arctic Ocean has yet to be determined. The ice-cap in Canada has been estimated to have exceeded two miles in thickness; and in the northern States the glaciation of the rock-surfaces and perched blocks have been traced on the hill-ranges to the height of 5000 to 6000 feet, which is the thickness the ice is presumed to have there attained. It covered and swept over, as in Britain, all the lesser inequalities of the ground, leaving exposed only the summit of the higher hills, such as the White Mountains, which also must have contributed their contingent of glaciers to this great mantle of ice.

Throughout the whole of this area the débris ground off the rocks by the powerful abrasion of the thick body of ice, with its adherent sand and pebbles, lies scattered over the surface; and where the rocks themselves are now exposed, they are found to have been rounded off, polished, and graven with parallel striæ in the manner before described. But more generally the surface has been left thickly covered with the wreck of the various strata the ice has passed over, consisting of sand, gravel, and blocks (often striated), and of an unstratified clay (boulder-clay) full of the same rock débris, forming an unstratified drift, which, with the exception of some scattered vegetable débris, is unfossiliferous. Trains also of the erratic blocks, carried southward on the ice for distances of from 1 to 50, and sometimes 100 miles or more, lie scattered over the surface, where they were dropped on the melting of the ice, or left perched at heights of 3000 to 4000 feet on the hills as the ice passed over them; but the great spread of the ice-sheet on its southern limits seems to have been unfavourable for the formation of terminal moraines. Some of the boulders measure 30 to 40 feet in length, and weigh 1000 to 1500 tons and more; one huge rock is estimated to contain 44,000 cubic feet of rock. Drift and boulders from the Canadian borders are spread over Connecticut, and reach to the Atlantic borders; they extend also from the Lake district to Ohio and Illinois.

In the north-western extremity of Arctic America, we meet with frozen ground and ice-cliffs similar to those present in northern Siberia. In 1818 Kotzebue discovered in Escholtz Bay, east of Behring's Straits, and in lat. 66° 15′ N., a cliff 20 to 90 feet high, composed of frozen mud and ice, and capped by a few feet of soil bearing moss and grass. At the foot of this cliff a considerable number of the bones of the Mammoth, Bison (?), Reindeer, Moose-deer, Musk-ox, and Horse were found, which had fallen out of the ice-cliff during the summer thaws. The cliff was afterwards visited by Captain Sir Edward Belcher[1], who brought many of these remains to England. One large tusk and other specimens are preserved in the Oxford Museum.

FIG. 219. View of the Ice-cliff in Escholtz Bay, Arctic America. (Reduced from the sketch by G. B. Seeman.) *The dark layer at top is surface soil,—the rest is nearly all ice.*

The warm currents of the Pacific, which now temper the severity of the coast climate of Alaska, seem to have exerted the same influence during the Glacial Period, for none of the glaciers which descend from the inland range reach the sea, nor do they appear to have done so in glacial times. Consequently there are none of the fiords which fringe the coast further south; and the terminal moraines of the old glaciers, described by Mr. Blake, remain at some distance from the coast, forming low hills covered by forest.

The shores of British Columbia, on the contrary, are indented by long and deep fiords, through which, as in Norway and Greenland, the old glaciers, now stayed further in, travelled out to sea, scoring and rounding off the rocks in these fiords to a great height above the sea-level[2].

[1] Sir E. Belcher considered that the ice formed only a facing to the cliff, but Kotzebue's opinion was subsequently confirmed by Captain Kellett.

[2] Dr. G. Dawson in 'Quart. Journ. Geol. Soc.' vol. xxxvii. p. 272, 1881.

Dr. Dawson records instances of hills 3200 and 3622 feet high exhibiting glacial polish and striation; but the most striking instance of the general glaciation mentioned by him is that of the Iron-mountain, at the junction of the Nicola and Coldwater rivers, the broad dome-like summit of which rises to the height of 5280 feet above the sea, and is heavily glaciated.

This great ice-sheet had its origin in the Rocky Mountains, and spread southward and seaward, riding over all the minor irregularities of surface. Throughout the greater part of this area it has left a coating of Boulder-clay, which extends the whole length of the coast district of British Columbia. The glaciation extended also over Queen Charlotte and Vancouver Islands; and the great straits between these islands and the mainland were filled by enormous glaciers. This important ice-sheet seems therefore to have covered, for a length of 400 miles or more, the plateau between the Rocky Mountains and the Coast Range, and to have escaped, as the ice does now in Greenland, through transverse valleys and fiords intersecting the latter.

Phenomena of a similar character, but with gradually contracting limits, extend southward through Oregon and Colorado. The glaciation extends both east and west of the great chains of the inland mountains and of the Coast Ranges; the greater mass of the ice, however, was on the west side. On the western slopes of the Sierra Nevada in California, glacial phenomena are wide-spread and well-marked.

The effects of ice-action are not confined to the more temperate climates of America. Mr. Belt[1] has recognised in the tropical districts of Central America boulder-clays and moraine-débris of old glaciers on the hills and slopes of the mountain-chains of Nicaragua at heights not greater than 3000 feet above the sea. One very steep range, fully 1200 feet high, was composed entirely of (or covered by?) old moraine matter. 'The clay was of a brown colour, and full of angular and subangular blocks of stone of all sizes, up to nine feet in diameter.'

Glacial Action in the Southern Hemisphere. Although owing to the more limited land-area, and the countries not being so well known, we are in possession of fewer facts relating to the glacial phenomena of the southern than of the northern hemisphere, those facts are nevertheless equally decisive as to the prevalence in late geological times of a Glacial Epoch, which there is reason to suppose was synchronous in the two hemispheres.

Little is known of the glaciers of the Andes in tropical regions. They are few, and on a small scale. It is, however, asserted that there are traces there, as in Central America, of their former extension to lower levels than now.

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[1] 'The Naturalist in Nicaragua,' p. 260.

Further south we have the evidence of Darwin and Agassiz respecting the extension of glaciers in Patagonia and Chili. The former[1] found the Tertiary plains, which, 100 miles inland, rise 1400 feet above the sea-level and bound the river Santa-Cruz, covered with numerous boulders of schistose, felspathic, and volcanic rocks, transported from the Cordilleras, of which the nearest slopes are 67 miles distant. These blocks are generally angular, and some are of great size. One of chlorite-schist measured 15 feet on each side, and projected five feet above the ground; another was 60 feet in circumference. In the Magellan Strait Darwin noticed the occurrence of thick unstratified masses of boulder-clay with fragments of rocks and boulders foreign to the locality. In other places the beds were finely laminated. He considered that the parent rock of some of the boulders could not be less than 120 miles distant. Cape Gregory, a headland about 800 feet in height, on the northern shore of the Strait of Magellan, is strewn over with blocks of crystalline rocks.

On the island of Chiloe, between 41° and 43° S. lat., Darwin found angular transported boulders in vast numbers up to the height of 200 feet. They consisted of syenite and granite; and, as he saw no such rocks in the island, he concluded they must have come from the Cordilleras. A few of the boulders were imbedded in a stratified gravel, others were in 'hardened mud' (boulder-clay).

Darwin was unable to obtain precise data for determining the age of this boulder-formation, though from the position of a raised beach, with existing species of shells, at a height of 350 feet, and other circumstances, he was led to conclude that 'it must have been accumulated since the commencement of the Post-Pliocene era or but little before it.'

We have the further testimony of Agassiz in 1872[2] of distinct glacial action in these regions. He remarks that in the Strait of Magellan unquestionable *roches moutonnées* were seen on the Fuegian coast opposite Cape Forward. In Port Gallant large boulders were observed, some six feet across, one 12′ × 6′ × 5′, well polished and striated. In Fortescue Bay there are similar scratched boulders; and also glacier-scratches on the rocks, with a W.N.W. trend. Glacial phenomena continue from this region to Jerome Point, which is itself well polished, especially on the south side. Again, York-River valley, which trends north, is smoothed on both sides, and so also is a gorge opposite, showing that the denudation was not due to an agent following the E. and W. course of the Magellan Strait. The two heads of the narrowest parts of the Strait are beautifully polished and rounded. Similar glacial effects were observed in Borgia Bay; and Pourtales traced them up a peak to a height of about 1500 feet above the

[1] 'Trans. Geol. Soc.' 2nd Ser. vol. vi. p. 415.
[2] 'Amer. Journ. Sci.' vol. iv. p. 135.

sea. In Glacier Bay and at other points there is evidence that the glacier once had a much greater extension than now. Professor Agassiz concluded from the character of the N. and S. sides of the hill-summits in Fuegia, and other facts, that the movement of the ice was to the north, and independent, for the greater part, of the present slopes of the land.

The region over which Professor Agassiz states that he observed glacial phenomena in South America includes all of the continent south of 37° of South lat., both on the Atlantic side (Gulf of St. Matias) and the Pacific side. At Talcahuano on the coast of Chili, in 36° 45′ S., large erratic boulders and *roches moutonnées* were observed on the hills of Hualpen at the mouth of the Biobio. In the Bay of St. Vincent, between Concepcion and Arauco, there was 'a magnificent polished surface,' with well-marked furrows and scratches upon the slope of a hill a few feet above tide-level, and this in latitude 37°. This was said by Professor Agassiz to be as well preserved as any he had seen under glaciers of the present day. The course of the scratches is east and west, but some cross the main trend and run south-east.

South Africa. Mr. G. W. Stow [1] considers that the denudation of great part of the Katberg, Stormberg, Krome, and other ranges lying between the latitude of 30° and 33° S., in South-western Africa, with peaks rising to the height of from 5000 to 1000 feet, has been effected by the agency of ice. He states that in the long valley leading to Langfield, and in other places, there are large transverse mounds, upwards of 60 or 70 feet high, of drift and boulders, and large deposits of unstratified clays full of angular boulders of every size, from small gravel to masses of several tons, turned and tilted in every position. At Beaufort this clay is from 30 to 40 feet thick, and in the Stormberg some of the angular blocks rise 10 to 12 feet above the surface of the ground. The rocks also in many places are smoothed and rounded; but as he only noticed ice-scratches and groovings in one place on the Tarka, further observations are desirable.

Australia. Signs of supposed glacial action have recently been met with by Dr. Von Lendenfeld [2] on the Australian Alps in lat. 37° S. Around Mount Clarke, which rises to the height of 7256 feet, he found the rocks (granite) glaciated over a large area down to, but not below, the level of 5800 feet above the sea. The evidence has been considered insufficient; but, if the photographs exhibited in the Australian section of the 'Colonial and Indian Exhibition' referred to that range (or any other in Southern Australia), there can, I think, be no doubt of the true glacial character of those surfaces.

New Zealand. The Alpine range which extends north-east and

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[1] 'Quart. Journ. Geol. Society,' vol. xxvii. p. 534, 1871.
[2] Ibid. vol. xli. p. 103.

south-west through the South Island of New Zealand, exhibits some remarkable instances of glacier-action, past and present. The culminating peak of Mount Cook attains a height of 13,200 feet. On the eastern side of the range, the Tasman Glacier descends to within 2772 feet of the sea-level; but on the west coast the Francis-Joseph Glacier descends to the level of 708 feet. There was a similar difference of level with the old glaciers, some of which descended to the sea-level. Dr. Hector considers that during the Glacial Period the country stood about 2000 feet higher than it does now; for on the south-west coast there are deep sea-lochs, such as that forming Milford Sound and others adjacent, in lat 44° S., which have been filled and ploughed by ice to the depth of 1800 feet. On the east coast, on the other hand, the old glaciers have generally left their moraines on the plains at the foot of the mountains, though in some cases these extended to the coast and form the present sea-cliffs. Sir Julius von Haast[1] assigned a length of about sixteen miles to the modern Tasman glacier, whereas the old Waitangs glacier of the Glacial Period had a length of 78 miles. The erratic blocks are sometimes of very great size. A boulder of contorted clay-slate, imbedded in the centre of the Bullhead moraine, is from 30 to 40 feet in diameter.

The quantity of detritus in the mountains is astonishing. 'Mountain-sides rising 5000 to 6000 feet above the valleys are often covered from their tops to the bottom with a continuous talus of débris, so that not one projecting rock can be seen.'

Nowhere in the temperate zone are clearer signs of the glaciation of a large district in the Pleistocene period to be met with than in the New Zealand Alps.

The accompanying Map exhibits the present extent of ice on the land and the limits of the floating ice on the sea in both hemispheres[2]; and also the probable extent of the land-ice during the Glacial Epoch.

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[1] 'Quart. Journ. Geol. Soc.,' vol. xxi. p. 130; vol. xxiii. p. 342.

[2] From the Admiralty and other charts.

Prestwich's Geology, Vol. II. Clarendon Press.

CHAPTER XXX.

THE QUATERNARY PERIOD (*continued*).

THE POST-GLACIAL AND LATER PLEISTOCENE DEPOSITS.

RETREAT OF THE ICE-SHEET. RISE OF THE LAND. ORIGINAL IRREGULARITIES OF SURFACE. OLD AND NEW RIVER-CHANNELS. THE VALLEY-DRIFTS. BEDFORD. GROUND-ICE. ITS EFFECTS IN ARCTIC COUNTRIES. FORMER RATE OF RIVER-EROSION. HIGH-LEVEL GRAVELS. ORGANIC REMAINS. LOW-LEVEL GRAVELS. ORGANIC REMAINS. PALÆOLITHIC WORKSHOP AT CRAYFORD. DISTRIBUTION OF PALÆOLITHIC IMPLEMENTS IN ENGLAND. TYPES. EARLY OBJECTIONS. VALLEY OF THE SOMME: AMIENS: ABBEVILLE. OTHER PLACES IN EUROPE. AFRICA. WESTERN ASIA. INDIA. IMPLEMENTS IN THE LATERITE BEDS AND NARBADA DRIFTS. UNIFORMITY OF SHAPE OF THE PALÆOLITHIC IMPLEMENTS. AUSTRALASIA. THE VICTORIA 'LEADS.' NORTH AMERICA. THE CHAMPLAIN PERIOD. THE CONNECTICUT TERRACES. VOLUME AND FORCE OF THE OLD RIVERS. MARINE TERRACES. SHELLS. QUATERNARY MAMMALIA. SOUTH AMERICA.

Retreat of the Ice-Sheet. After the period of maximum cold, when permanent ice extended over the large area indicated by the light-blue colour in the map, p. 468, the great ice-sheet gradually yielded to the influence of the returning warmth, and began its retreat. The retreat, however, was not continuous and unbroken, but was interrupted at intervals by vicissitudes of climate dependent upon meteorological causes, such as operate at the present day, and upon those contemporary physiographical changes before described, of which we can only conjecture the conditions. Consequently the retreat of the glaciers is marked by a succession of smaller moraines formed during these periods of colder seasons, either by the delay in the retreat, or by the temporary advance, of the glaciers. Thus, the great terminal moraines of the Italian Alpine glaciers and many others are, as before mentioned, succeeded in the inner side by small parallel ridges at greater or less intervals, the spaces between them forming flat valleys, the result of times of continuous retreat. As the ice melted, the vast volume of water liberated by the accumulated ice and snow produced floods, which scored the plains and deepened the river-valleys, the effects being greatest wherever the land was slowly rising.

Rise of the Land. Other causes, however, operated in fashioning the surface of the land, as well during this as during antecedent periods. Independently of the action which the waves exercise on the coast or on slowly rising land, there must have been a scour on the sea-floor proportioned to the rapidity with which it emerged. The rise might have been slow, and the effects almost imperceptible, or it might have been quick, and the scour of vast power (see Vol. I. pp. 83 and 222). Even a very slow rise, or a rise *per saltum* of a few feet at a time—as those which have accompanied some of the great earthquakes on the coast of South America—would exercise enormous excavating power. The rate of rise we can never hope to know. We can only judge by the results. That it may have been at times a most powerful agent of denudation there can be no doubt.

Original irregularities of surface. An ordinary sea-floor presents a surface of considerable irregularity. In seas of moderate depth the currents will in one place excavate broad channels, and in others they pile up the débris in banks. As the floor rises, these channels may be deepened and the banks may be removed, but in no case is it probable that the sea-bed can reach the surface without the irregularities being increased, so that when it appears above the water-level it presents an uneven surface of swelling ridges, with channels of various lengths and intricacy converging towards the lowest point at which the water escapes. A section of such a surface presents therefore a flowing outline as under, and shows the limits to which such action is confined, and where rain- and river-action commences.

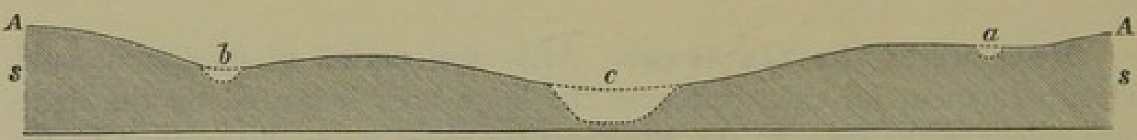

FIG. 219*. Diagram showing the surface of a newly emerged land before the insetting of River-action.
A, A. Original surface of denudation by other than river-action. a, b, c. Valleys formed by river-denudation. s. The emerged strata.

Raised and converted into dry land, the depressed portions become channels in which the rain-water collects and along which it finds its way to the adjacent seas. At first these rivers are without definite channels, and spread over a considerable breadth of ground. Eventually they select more definite lines, which they follow permanently, and gradually deepen their beds, which ultimately become restricted to those narrower channels represented by the dotted lines in Fig. 219*.

Old and new River-channels. In old lands these causes may have been in operation at any period anterior to Glacial times; but in parts of England, and other places recently raised, their action dates after the spread of the Boulder-clay, although the old surfaces may have been seamed by Pre-glacial rivers, whose channels became filled up by the glacial deposits. Sometimes, these old lines of drainage may have been re-opened; at other times fresh channels were formed, and different lines of drainage established.

The Valley-drifts. The new lands remained for a certain time bare and uninhabited, so that the earliest and highest drift-beds deposited by the rivers were unfossiliferous. As the land became clothed with a vegetation and a fauna derived from adjacent districts, portions of this flora and fauna, swept down by the floods, became preserved in the sands, loams, and gravels deposited by the river: and this continued during the remainder of its history. It would follow that the lowest beds should be the most fossiliferous. It may also be noticed that, whereas in sedimentary marine deposits the higher beds are necessarily the younger, it is the reverse with the valley-drifts, for in this case the beds on the higher levels are older than those at the lower levels. The gradual wear and deepening of the valley is represented in the following diagram:—

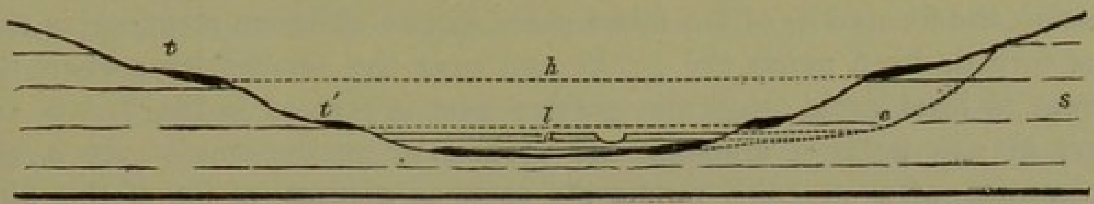

FIG. 220. Diagram-section of a Valley formed by ordinary River-action.
h. Original level of the River-bed. s. Horizontal Strata cut through by the river. l. Level at a later period. t, t'. Terraces of Gravel and Loess left by the River when it flowed at those levels. e. Line marking a wider erosion and removal of the Terraces. a. Modern Alluvium. Present River-channel.

Examples of this operation in Post-glacial times are to be met with in those parts of Bedfordshire, Cambridgeshire, and Norfolk, where the Boulder-clay caps Cretaceous and Jurassic strata, and forms low plateaux, through which the rivers have excavated their channels. A good case is that of the valley of the Ouse at Bedford, where in the middle of the broad valley there is a low hill (171 feet) capped by gravel and sand with fluviatile shells, remains of Mammoth, Reindeer, etc., and Flint implements; whilst at the lower level of 125 feet there is another bed with a larger number of mammalian remains, including the Hippopotamus; the *Unio littoralis* is also found in this lower bed.

The Boulder-clay and the underlying horizontal Jurassic strata were here originally continuous across the valley. The old river, swollen annually by the melting of the winter snow and water from the retreating ice-sheet, spread during flood across the whole breadth of the valley, undermining its banks and gradually excavating a broad channel, while afterwards it ran in the more contracted channel at the lower level.

Ground-Ice. But this was not the only means by which the rivers of these Glacial and Post-glacial times deepened their channels. In all Arctic countries ice forms at the bottom of the rivers as well as on the surface, and generally on the latter first. When the water is reduced to and below 32° F., although the rapid motion may prevent freezing on the surface for a time, any pointed surfaces at the bottom of the river, such as stones and boulders, will determine (as is the case with a saturated saline solution) a sort of crystallisation, needles of ice being formed, which gradually extend from stone to stone and envelope the bodies with which they are in contact. By this means the whole surface of a gravelly river-bed may become coated with ice, which on a change of temperature, or of atmospheric pressure, or on acquiring certain dimensions and buoyancy, rises to the surface, bringing with it the loose materials to which it adhered. Colonel Jackson[1] remarks in speaking of this bottom-ice that 'it frequently happens that these pieces, in rising from the bottom, bring up with them sand and stones, which are thus transported by the current. . . . . When the thaw sets in, the ice becoming rotten, lets fall the gravel and stones in places far distant from those whence they came.' Again, Baron Wrangell[2] remarks that 'in all the more rapid and rocky streams of this district [Northern Siberia], the formation of ice takes place in two different manners; a thin crust spreads itself along the banks and over the smaller bays where the current is least rapid; but the greater part is formed in the bed of the river, in the hollows amongst the stones, where the weeds give it the appearance of a greenish mud. As soon as a piece of ice of this kind attains a certain size, it is detached from the ground and raised to the surface by the greater specific gravity of the water; these masses, containing a quantity of gravel and weeds, unite and consolidate, and in a few hours the river becomes passable in sledges instead of in boats.' Similar observations have been made in America, but instances need not be multiplied, as it is a common phenomenon in all Arctic countries, and is not uncommon on a small scale even in our latitudes (Vol. I. p. 192).

Former Rate of Wear. The two causes combined—torrential river-floods and rafts of ground-ice, together with the rapid wear of the river-cliffs by frost—constituted elements of destruction and erosion, of which our present rivers can give a very inadequate conception; and the excavation of the valleys must have proceeded with a rapidity with which the present rate of erosion cannot be compared; and estimates of time founded on this, like those before mentioned on surface-denudation (Vol. I. p. 108), are therefore not to be relied upon. Owing however to the continual lateral wear, much of the earlier river-drift or gravel left at first on the sides of the valleys has been removed and lost in the manner before described, and shown in Fig. 220. But the lower-level gravel is commonly left.

The High-level gravels are generally coarser and contain fewer subordinate beds of sand or clay than those on the lower levels, and organic remains are more rare. In the greater number of cases, they contain neither shells nor bones. Yet, unless early Man lived upon roots and fruits (which in these latitutes at that time is improbable), it is certain

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[1] 'Journ. Roy. Geogr. Soc.' vol. v. 1835, p. 2 et seq.

[2] 'Narrative of an Expedition to the Polar Sea,' Sabine's translation, 2nd ed., pp. 5, 63, 258.

that animals must have existed in all those districts where he was present. Thus in the gravel on the cliffs between Herne Bay and the Reculvers, and in that around Southampton and Reading, and in many other places, flint implements—the work of early man—are not rare. Yet not a trace of contemporaneous animals has been found in those beds. It is not however difficult to account for their absence. These gravels are exceedingly permeable, and when exposed on hills or slopes, a large portion of the rainfall passes through, and often lodges in them; and this process in the course of long ages has sometimes removed every trace, not only of calcareous animal matter, but even of calcareous stones, from these beds, leaving only the insoluble residue of siliceous and argillaceous matter, with rock fragments and pebbles of similar composition (see Vol. I. p. 144). Bones would necessarily disappear under conditions which could dissolve this amount of calcareous matter.

In those cases, however, where the gravel is on a lower level, and the percolation has not been so long and persistent; or where the high-level gravel has been protected by an overlying bed of clay or loam (loess), the remains of the fauna contemporary with early man have been preserved, as in the typical case of St. Acheul near Amiens. The sand and gravel are there covered by a thick bed of brick-earth, which has excluded the surface-waters, and so preserved the organic remains from destruction.

Organic Remains. Sometimes the fossils are confined to the lower-level gravels; more rarely to the upper gravels; and occasionally they occur in both. The character of this land and fresh-water fauna is very nearly alike in both levels. The more common forms are,—

Mollusca (see Plate XVI).	*Mammalia.*
Cyclas (*Sphærium*) cornea, *Linn.* Fig. 16.	Elephas primigenius, *Blum.*
Pisidium amnicum, *Müll.* Fig. 14.	,, antiquus, *Falc.*
Ancylus fluviatilis, *Linn.* Fig. 19.	Rhinoceros tichorhinus, *Cuv.*
Bithynia tentaculata, *Linn.* Fig. 21.	Ursus spelæus, *Blum.*
Limnæa peregra, *Müll.*	Hyæna spelæa, *Gold.*
,, palustris, *Linn.* Fig. 13.	Felis spelæa, *Gold.*
Planorbis spirorbis, *Linn.* Fig. 17.	Bos primigenius, *Boj.*
Valvata piscinalis, *Müll.* Fig. 20.	Bison priscus, *Boj.*
Helix hispida, *Linn.* Fig. 25.	Equus fossilis, *Owen.*
,, pulchella, *Müll.*	Cervus elaphus, *Linn.*
Pupa marginata, *Drap.* Fig. 27.	,, tarandus, *Linn.*
Succinea oblonga, *Drap.* Fig. 22.	Castor Europæus, *Linn.*
Zua lubrica, *Müll.*	Sus scrofa, *Linn.*

A few species seem peculiar to the lower gravels, among which are,—

Cyrena (Corbicula) fluminalis, *Müll.* Fig. 15.	Hippopotamus major, *Nesti.*
Unio littoralis, *Lam.* Fig. 13.	Rhinoceros megarhinus, *Christ.*
Marine shells occasionally.	Ovibos moschatus, *Linn.*

But there is still, however, some uncertainty about the exact differences in the range and localisation of species in these beds.

The most abundant of the Mammalian remains, especially in the Low-level drift, are those of *Elephas primigenius* or Mammoth, *Elephas antiquus*, *Rhinoceros tichorhinus* or Woolly Rhinoceros, *Cervus elaphus*, *Bos primigenius*, *Equus caballus fossilis*. Large herds of the Mammoth must have ranged over Northern Europe. In digging the foundations for the New Schools at Oxford, not fewer than six lower jaws and several tusks were found; and at the railway ballast-pit at Yarnton the teeth and tusks of no fewer than fifty individuals were met with.

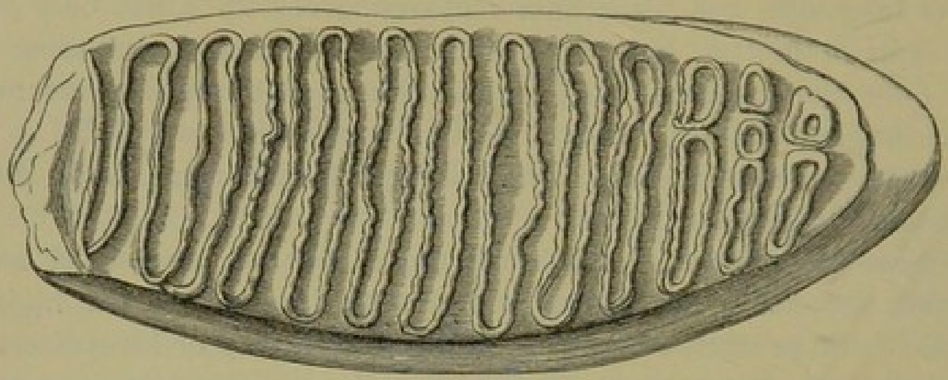


FIG. 221. *Tooth of Elephas primigenius*, Blum.

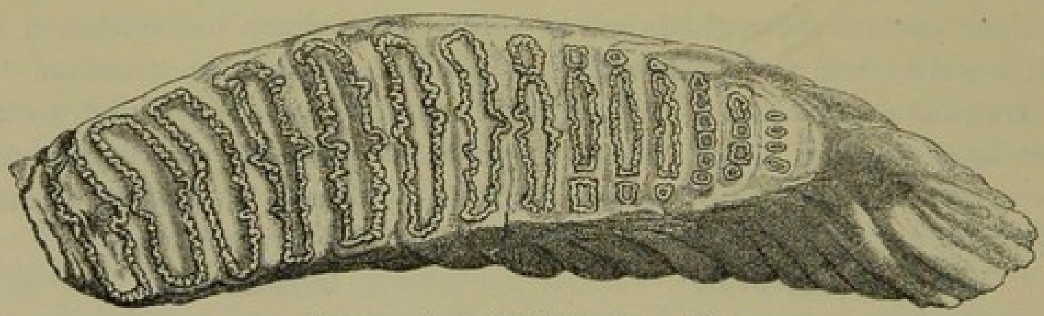


FIG. 222. *Tooth of Elephas antiquus*, Falc.

The remains of Hyæna, Bison, Felis, and Cervus are more common in the ossiferous Caves (Fig. 239, p. 495).

Entomostraca are occasionally common in some of the finer lower-level sediments; amongst them are the characteristic *Candona candida* and *Cypris Browniana*.

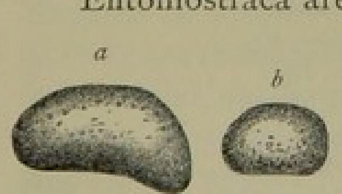


FIG. 223. Pleistocene Entomostraca.
a. Candona candida (Müller), $\frac{12}{1}$.
b. Cypris Browniana, Jones, $\frac{12}{1}$.

Determinable remains of plants are very rarely met with, though fragments of decayed wood (usually coniferous) are not uncommon. At Hoxne, the Oak, Yew, and Pine were recognised.

The character of these old rivers was, however, so torrential, and their higher drift-gravel so coarse, that it is only in the more sheltered and protected places that the delicate fluviatile and land shells have been preserved.

In the Low-level gravels, which consist, in like manner, of alternating loose beds of gravel, sand, and clay, the greater shelter afforded, and the more common occurrence of argillaceous and arenaceous beds, have led to the more frequent preservation of the organic remains. Thus, at Grays-Thurrock in Essex the Thames then flowed up to the foot of an old chalk cliff, and deposited in this sheltered spot some sands and clays over the basement gravel. These beds are full of well-preserved land and river shells, all belonging to recent species, and living in this country, with the exception of the *Unio littoralis* and *Hydrobia marginata*, still however living in France, and *Cyrena fluminalis*, now extinct in Europe, but living in the Nile and some of the rivers of Thibet and other parts of Central Asia. This shell occurs at Grays-Thurrock, Ilford, Crayford, Summertown near Oxford, and a few other places, in profusion. At Grays leaves of plants were found in one of the clay beds, and in another the nearly entire skeleton of a Mammoth was discovered, but unfortunately it was in a very decayed state, and no pains were taken to preserve it.

Another section of special interest is one on the south side of the Thames at Crayford in Kent. In this case also the river flowed when in flood at the foot of an old chalk cliff, but when the waters were low, a sandy shore of some extent was left dry. To this strand it would seem that early man resorted for the manufacture of some of the simple implements which he made from the flints of the adjacent Chalk.

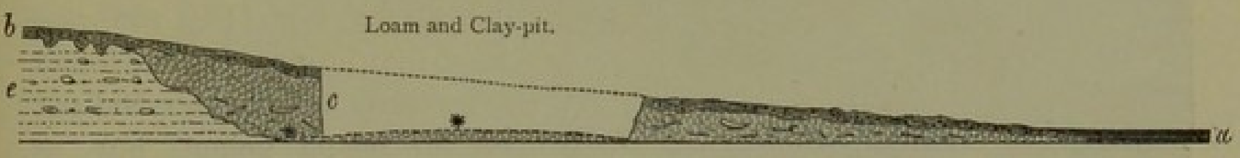


FIG. 224. Section of the old Palæolithic Floor near Crayford.
a. Alluvial Beds. b. Brown Gravelly Clay. c. Light-coloured Loam, Sand, and Clay, with fluviatile and land shells, remains of the Mammoth, Woolly Rhinoceros, etc., and Palæolithic flint Implements. * - - - - *Line of old palæolithic floor. e. Chalk with large flints.*

Mr. F. C. J. Spurrell[1] has made the curious discovery that at the depth of about 20 to 30 feet below the present level of the surface, there are scattered on a level (*) a number of flint flakes, evidently struck off for a purpose[2], together with a few larger implements. Besides these, a great number of waste chips and flakes, such as may be now found on the ground in any of the gun-flint workshops of Norfolk, were strewed about. Collecting these flakes and chips, Mr. Spurrell found that many of them fitted one another, and on taking all which occurred within a small radius around, he discovered that they not only fitted, but that in many cases the whole of the broken-up mass of flint was there; and on putting the pieces together, he was able to reconstruct the original massive chalk-flints, some of which were of large size. Here therefore we have evidently a case

[1] 'Quart. Journ. Geol. Soc.,' vol. xxxvi. p. 544.

[2] A fragment of flint knocked off artificially is easily recognised by the 'bulb of percussion,' caused by the conchoidal fracture flint takes when struck a sharp blow with a hammer or hard stone.

in which the flints were worked on the spot, left probably by the workers owing to a sudden rise of the river, and subsequently covered up by the flood-sediments, which accumulated to the thickness of 20 to 30 feet above the lowest of those old floors. Associated with the flints, and also scattered in the beds below and *above* them, are the tusks, teeth, and bones of Mammoth, Rhinoceros, Horse, Ox, Deer, etc., together with the shells named in the foregoing lists, though not in such abundance as at Grays-Thurrock.

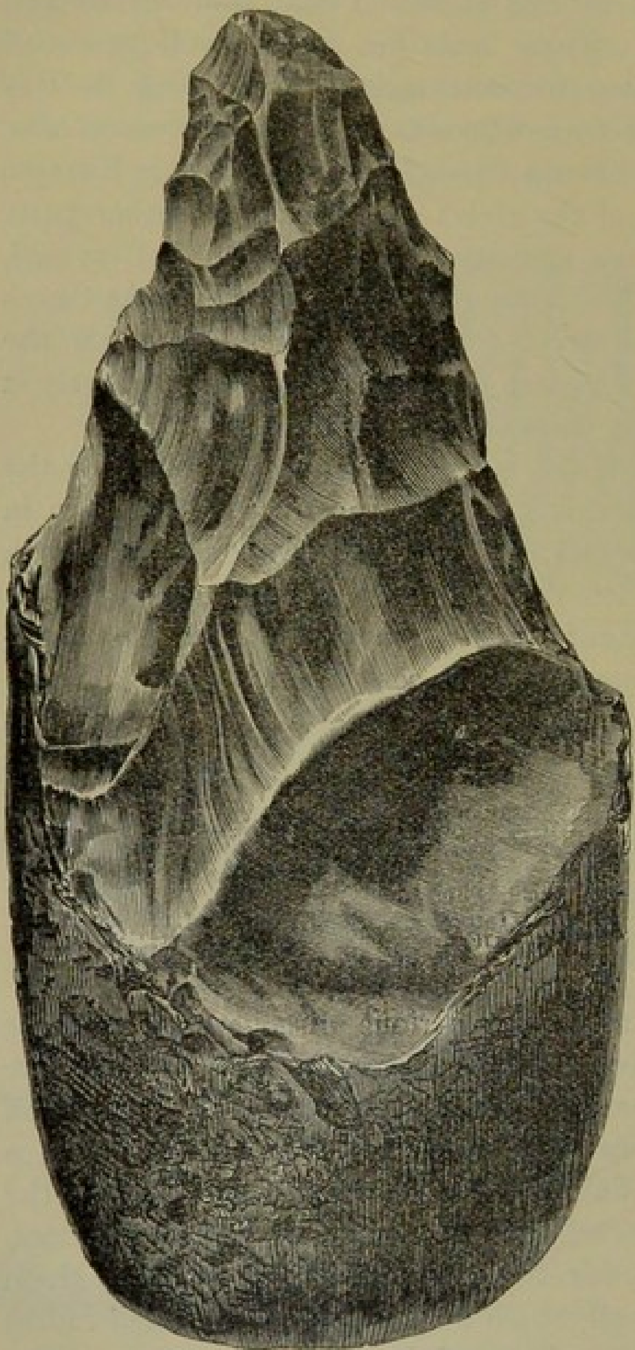


FIG. 225. *Implement from the Gravel capping the cliff between Herne Bay and the Reculvers*, nat. size. (Evans.)

Distribution. Lower down the Thames Valley these implement-bearing gravels have been found at several levels. Between the Reculvers and Herne Bay a high-level gravel caps the top of a London-Clay cliff 80 feet high (Fig. 166), and large flint implements are found from time to time washed out on the beach below; but, as before mentioned, no contemporaneous fossils of any kind are met with in this bed of gravel, which is from eight to ten feet thick. In some of the adjacent valleys, however, there is a low-level drift-bed, with the usual fluviatile shells and flint implements; small sections of this bed are exposed on the coast.

The same condition of things obtains at Salisbury, where the high-level flint gravels of Milford Hill and Bemerton contain flint implements, but no Mammalian remains, whereas in the drift and valley-gravel at Fisherton, on a level 100 feet lower, flint implements, together with land and fresh-water shells of the usual recent species and Mammalian remains of the extinct forms, including the small *Spermophilus* (Fig. 227), have been found.

Palæolithic implements are also found in the valley-gravels in the neighbourhood of Hackney, Acton, and other places near London; again at Hill Head on the shore of the Solent near Portsmouth, Bournemouth, in

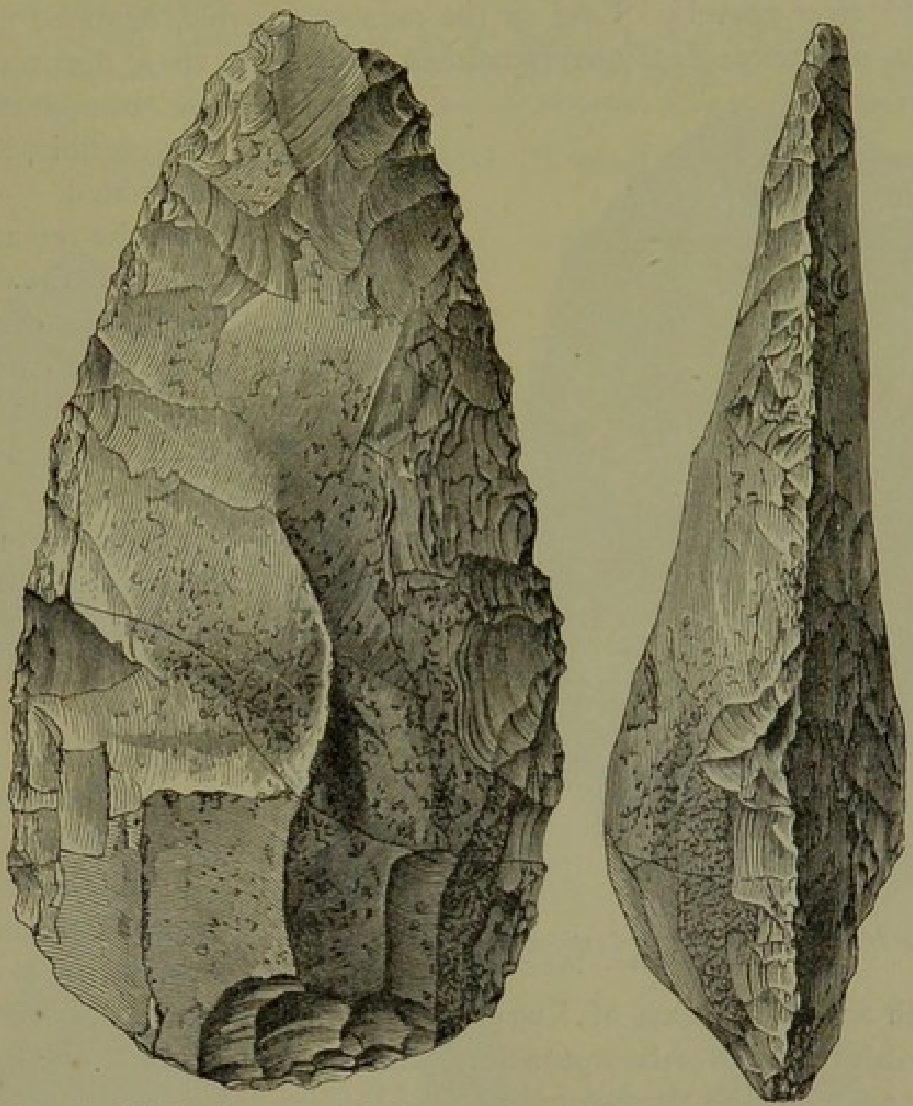


FIG. 226. *Flint Implement from the Gravel on the top of Milford Hill, Salisbury, about 100 feet above the level of the adjacent valley of the Avon;* scale ½ size. (Evans.)

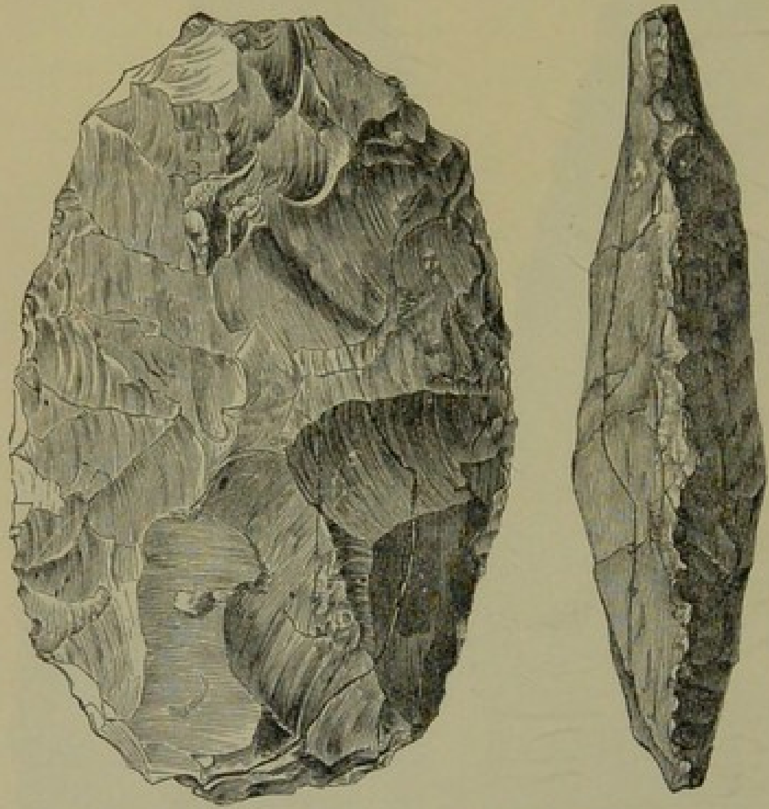
the Isle of Wight, the valley of the Axe near Axminster[1], and in the east of England at Shrub-Hill near Feltwell, Santon Downham near Thetford, Icklingham, and several other places. At the original site at Hoxne near Diss, where they were discovered in large numbers at the end of the last century (but the discovery had dropped into oblivion), they are associated with a few fluviatile shells and Mammalian remains. At Barnwell near Cambridge, where the shells, including the *Cyrena fluminalis*, are numerous, and Mammalian remains common, only a few flint implements have been discovered. At Oxford also very few Palæolithic implements have been met with in the

FIG. 227. *Jaw of Spermophilus from the Drift, Salisbury.* (After Falconer.)

[1] Those found here are made of chert from the neighbouring Greensand.

gravel, in which the lower jaws, teeth, and tusks of the Mammoth occur very frequently.

It is not difficult to account for the presence of these implements in the old river-gravels. Lost in the pursuit of game, dropped in fording the rivers, or unexpectedly overwhelmed by freshets, these flint tools, which are comparatively indestructible, have been imbedded, generally with the remains of the animals then inhabiting these districts, in the river-drifts and gravel. But besides their occurrence in this manner, they have been discovered in several localities[1] lying on the surface of the ground, often in considerable numbers and at all levels; these cases are more difficult to account for.



Flint Implement from the gravel capping the low cliff near Hill Head, ½ size. (Evans.)

These Palæolithic implements thus spread over so great a part of the South and South-east of England, have not yet been discovered north of Oxfordshire and Northamptonshire, with the exception of one found near Bridlington. Beyond those counties Neolithic implements of later man alone have been met with. The subject is too large to dwell upon further; but the reader will find an account both of the Palæolithic and Neolithic implements[2], with the localities at which they occur and the conditions under which they are found, in the valuable and exhaustive work on this subject by Dr. John Evans[3], to whom I am indebted for the use of these woodcuts.

Types. The forms of these tools or weapons of early man are very limited in number. Omitting the few varieties, they may be reduced roughly to the following:—

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[1] In Kent—in the Valley of the Darent, around Ightham, and Limpsfield; and at some other places.

[2] 'Palæolithic' stone implements are those which are in association with the extinct Mammalia; 'Neolithic' applies to those found in association with the existing fauna, and belonging to the period preceding the Bronze Age.

[3] 'Stone Implements of Great Britain.' Longmans, 1872.

1. Flakes, for cutting, scraping, and drilling . . . . (Fig. 234).
2. Circular and semicircular flakes chipped at the edge, used for scraping skins or wood.
3. Pointed implements with a rounded butt-end, probably for holding by the hand (Fig. 225).
4. Pointed implements, possibly for fixing to the end of a shaft as weapons for the chase or defence . . . . (Fig. 229, *c*).
5. Implements with broad cutting ends, possibly fixed in handles and used for splitting wood, or for cutting holes through the ice for fishing . . . (Fig. 226).
6. Ovoid implements, which may have been used for chopping, or as missiles (Figs. 228, 229, *b*).

All this of course is very conjectural. If wood or sinews were employed

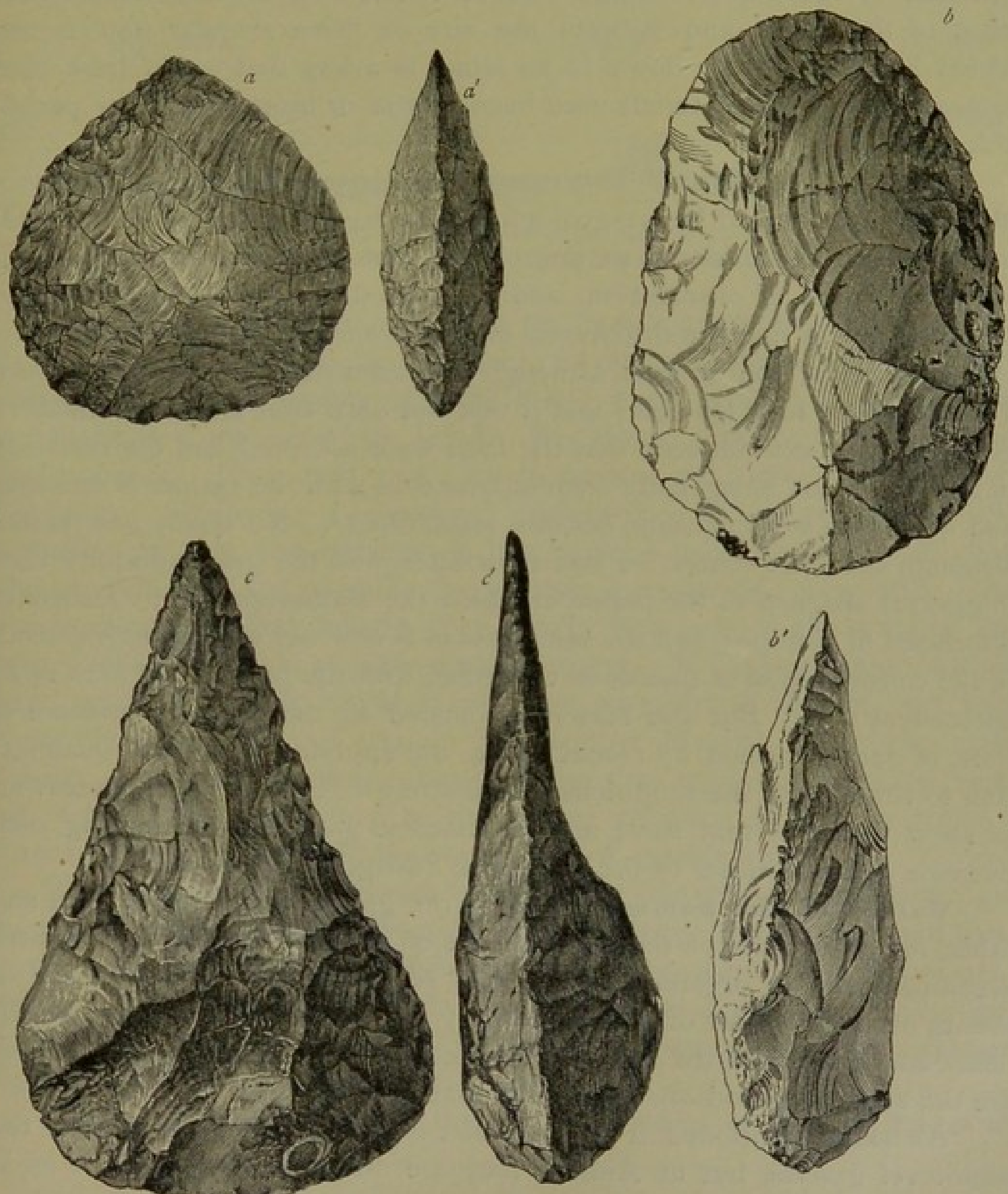

FIG. 229. *Front* (*a*, *b*, *c*) *and side* (*a'*, *b'*, *c'*) *views of Flint Implements of three types from Santon Downham, Suffolk*, ½ nat. size. (Evans.)

to mount any of these implements, they have long since decayed away and disappeared. The workmanship is generally of a very rude description.

None of the implements are ground or polished. The shape was obtained entirely by chipping. The simple flakes are such as were made also at the later Neolithic period, and flakes similar to these are produced at the present day in the process of making gun-flints; but, with this exception, all the other forms present types of their own, which, though analogous to, are distinct from those of the Neolithic period, and distinct from those made now by any uncivilised tribes still, or until lately, ignorant of the use of metals. Those selected for illustration comprise most of the types, and indicate the size of these singular implements, which have thus come down to us intact in a way that would have been impossible had the materials used been of iron or bronze, or other perishable substances.

Early Objections. This remarkable phase in the Early History of Man had long loomed before geologists from reported discoveries in caves; but these were considered so improbable, that they were invariably attributed to errors of observation, and considered inadmissible. The same fate attended at first the discoveries of M. Boucher de Perthes in the Drifts of the Valley of the Somme, although they admitted of easier verification. They too were long ignored; and it was not until after much confirmatory evidence had been adduced that the facts were accepted, and the certainty of the specimens being truly contemporaneous with the extinct Mammalia, and of human workmanship, became established [1]. No doubt one reason, although there are others, for this reluctance, was the great antiquity then in general assigned to the period at which the Mammoth and its associates flourished in Europe; and the same reason is now not without its influence in the consideration of questions connected with the presence of Man at an antecedent date. But this reason is founded on the use, as a measure of time, of data furnished by recent times, and applying it without qualification to times when the conditions were entirely different. I shall endeavour to show presently that there are no sufficient grounds for assigning such extreme duration either to the Glacial or Post-glacial times.

Valley of the Somme. This is the ground which, more than any other, in consequence of the completeness of the sections and the frequent accompaniment of organic remains, has served to show the sequence of events during this part of the Quaternary Period, and to establish the evidence connected with the early appearance of Man. The two main centres are the neighbourhood of Amiens and that of Abbeville.

As before mentioned, it is rarely that organic remains are found in the high-level gravels, but at Amiens they are met with there as well as in

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[1] Boucher de Perthes, 'Antiquités Celtiques et Antédiluviennes,' 1847–60; the Author, in 'Trans. Roy. Soc.,' May, 1859; Dr. John Evans in the 'Archæologia,' June, 1859; M. Gaudry in 'Comptes Rendus' for October, 1859; J. W. Flower in 'Quart. Journ. Geol. Soc.;' and others.

those of the lower levels. At St. Acheul the gravel-beds are on the brow of a hill 97 feet above the River Somme, and about 70 feet above the low-level beds. They contain in places numerous fluviatile and land shells (those given in list at p. 473 and others [1]), with teeth and bones of the Mammoth, Rhinoceros, Horse, Reindeer, and Red Deer, but not of the Hippopotamus. Flint implements, chiefly of the large pointed type (the '*haches*' and '*langues de chat*' of the workmen), are common [2]—some rolled and worn, others as sharp and fresh as when first made.

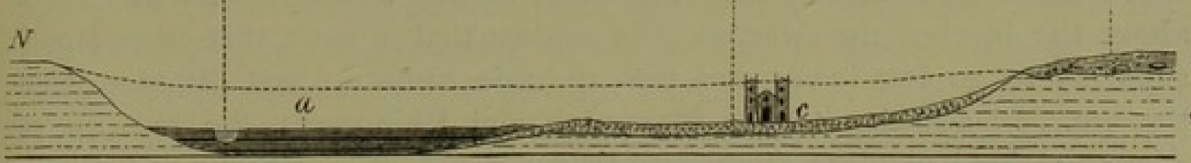

FIG. 230. Section across the Valley of the Somme at Amiens.
a. Alluvial beds. c. Low-level Valley Gravels. c'. High-level Valley Gravels. e. Chalk.

In addition to his working tools, it has been suggested that man at this place made use of a simple ornament, for in association with the other remains there are a number of small round white bodies [3], many of them perforated in a manner which led Dr. Rigollot to suppose they had been used as beads. They are in fact a small, more or less globular Hydrozoan, *Porosphæra* (*Millepora*, *Coscinopora*) *globularis*, Phillips, with a central depression or hole, and common in the Upper Chalk (see Fig. 154); but whether collected and used for the purpose here named, or whether, like the accompanying flint shingle, they merely form part of the mass of the worn Chalk débris, it is scarcely possible to say. It has been asserted that these small bodies are found in numbers together, as though they had been strung together. Certainly the number through which the little cup-like depression penetrates seems greater than in specimens taken fresh out of the Chalk; this may be due to the selection of such specimens, if used as beads, or possibly the result only of outside wear.

The bedding of the gravel is extremely irregular and contorted, as though it had been pushed about by a force acting from above; and this, together with the occurrence of blocks of Tertiary sandstone of considerable size, leads to the inference that both are due to the action of river-ice. In the Seine Valley blocks of still larger size, and transported from greater distances, are found in gravels of the same age.

There is little difference in the organic remains of the two levels at

[1] For the complete list see 'Phil. Trans.' for 1864, p. 306.

[2] It is estimated that there is one specimen to every cubic metre of gravel. I have brought away at different times above 200 specimens, and the total number found at this one locality can hardly be under 4000.

[3] First thought to be a small sponge. It is extremely common in the chalk cliffs of Newhaven.

Amiens, except that in addition to the other Mammalian remains occurring in the high-level drift, the Hippopotamus is found in the lower.

It is otherwise at Abbeville. There, no organic remains are found in the upper gravels, in which flint implements are common, whereas the low-level sands and shingle are extremely fossiliferous. Besides all the ordinary fluviatile mollusca occurring at Amiens, a larger number of land-shells, including *Cyclostoma elegans* and *Pomatias obscurus*, together with a few specimens of the *Cyrena* (*Corbicula*) *fluminalis* and various marine shells,—*Cardium edule*, *Tellina solidula*, *Buccinum undatum*, *Nassa reticulata*, &c., —are found at Menchecourt. The level of this bed is now about 15 feet above the level of the river, so it is evident that it must then have stood some 25 to 30 feet lower, and that the tide came up that distance from the sea. In addition to the Mammoth and Rhinoceros, the remains of *Hyæna spelæa* have been discovered there.

Other Places in Europe. Flint implements are found under similar conditions in many of the river-valleys of other parts of France, especially in the neighbourhood of Paris; of Mons in Belgium; in Spain, in the neighbourhood of Madrid; in Portugal; in Italy, and in Greece; but they have not been discovered in the Drift-beds of Denmark, Sweden, or Russia; nor am I aware that there is any well-authenticated instance of the occurrence of palæoliths in Germany.

Loess. Closely connected with these valley-gravels are the loams and brick-earths which so frequently overlie and extend beyond them both in height and distance. The two are in fact intimately related, the gravels being the coarse débris and larger fragments carried down by the rivers during the rise of their waters and in flood, and the loam or silt (Loess) being the fine sediment deposited or lodged by the waters in flood and as they fell. With the thawing of the winter snow and ice, and the gradual melting of the great ice-sheets, the spring floods of all the rivers in and on the borders of the ice-covered lands must have been, as in arctic regions at the present day, of great volume and power.

The Loess partakes to a certain extent of the character of the local strata. As, however, the average lithological character of those in many of the river-basins is very much alike, so the Loess has commonly a very similar composition of fine argillaceous and siliceous, with more or less calcareous, matter,—the latter often removed by the percolation of the surface-waters (see Vol. I. pp. 32 and 90). The Loess varies in thickness from a few inches to several hundred feet, the result of successive inundations as the rivers decreased and their valley-channels fell to lower levels.

The organic remains found in the Loess are generally few in number and always of a character in accordance with the above view of its origin. They consist invariably of land and marsh shells, and land animals of the same species as those found in the gravel. Amongst the common shells found in it in this country and on the Continent are, *Pupa marginata*, *Succinca oblonga*, *Helix hispida*, *H. nemoralis*, *Cyclostoma elegans*, etc. (See Pl. XVI, figs. 24 to 26.)

Africa. Little is known of the Drift-beds of Africa. In Egypt General Pitt-Rivers found in an undisturbed bed of gravel on the sides of El Waddi, near Thebes, some flint flakes[1]; but no organic remains accompanied them to indicate their age, nor were there any implements of the special palæolithic type. Similar discoveries are reported from other parts of North Africa. In South Africa, however, stone implements of the European palæolithic type have been found at some places. Near Port Elizabeth they were discovered in a thin bed of gravel capping a hill rising 200 to 250 feet above the sea-level. They are of quartzite, and of the pointed form similar to Fig. 226. Other specimens were found 350 miles inland at the 'Junction.' One of these specimens of quartz-felsite is almost identical in form with Fig. 225. Unfortunately in neither case were they accompanied by organic remains, so their age is yet uncertain[2].

Western Asia. M. Louis Lartet[3] records several instances of the discovery of stone implements—some simple flakes, others of the peculiar palæolithic type—in Palestine and Babylonia; but in the absence of details of site and association, no conclusions can be arrived at respecting their history.

India. Thanks to the researches of the Government Surveyors and others, we are in possession of much more certain information about the stone implements of India. They were first found at depths of from five to ten feet in the low-level Laterite,—a brick-red detrital, argillaceous, and sandy conglomerate much impregnated with iron peroxide, and with grains of pisolitic iron,—occurring in the Madras district[4], and rising to heights of from about 200 to 300 feet above the sea-level. These implements, which are made of very hard quartzite, are much stained and often much worn. Their forms are exactly like those of the French and English specimens (Figs. 226, 228, and 229), only, owing probably to the nature of the stone, the workmanship is much ruder. There is little doubt of the Quaternary date of the deposit, which is possibly an old beach; but in the absence of fossils its precise age cannot be determined.

The drift deposits of the Narbada valley furnish us, however, with better evidence. These consist of alternations of beds of clay, sand, and gravel, of great thickness, rising to 100 feet above the level of the river[5]. They contain fresh-water shells (Planorbis, Bithynia, Limnæa, Melania, and

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[1] 'Journ. Anthropol. Instit.,' May, 1882.

[2] J. C. Rickard, 'Camb. Antiq. Soc.,' vol. v. p. 57, 1880.

[3] 'Géologie de la Palestine,' chap. xii.

[4] Bruce Foote, 'Mem. Geol. Survey, India,' vol. x. part 1; 'Quart. Journ. Geol. Soc.,' vol. xxiv; and 'Journ. Anthrop. Instit.,' p. 484, August, 1886.

[5] 'Manual of the Geology of India,' chaps. xv. and xvi.

Unio), and an Elephant allied to the existing Indian species; together with another and a Hippopotamus both belonging to extinct subgenera; also species of Bos and Rhinoceros. With these there was found a quartzite implement almost identical with some of the more pointed forms of Fig. 229, *b*.

The old gravels of the Godávari are chiefly composed of rolled agates and fragments of basalt derived from the surrounding igneous rocks of the Deccan. Bones of Mammalia (Elephas, Bos, etc.), it is said, some times occur in large numbers, and in one place an agate flake was found. Dr. Blanford also states that 'large numbers of chipped quartzite implements of human manufacture, and belonging to the same type as that discovered in the Narbada alluvium, have been found in various gravels in the Southern Máhratta country on the Malprabha and other affluents of the Krishna. The relations between the ossiferous gravels and those containing the implements are, however, somewhat obscure.'

Uniformity of Shape. It is very remarkable that the type of these palæolithic implements, although sometimes made of different materials, is so much alike in such different and distant parts of the old world, and, with very few exceptions, is unlike that of any of the neolithic or recent forms. With the art of grinding and polishing the implements, new forms were introduced, and local divergences established, in marked contrast with the uniformity which prevailed in palæolithic times.

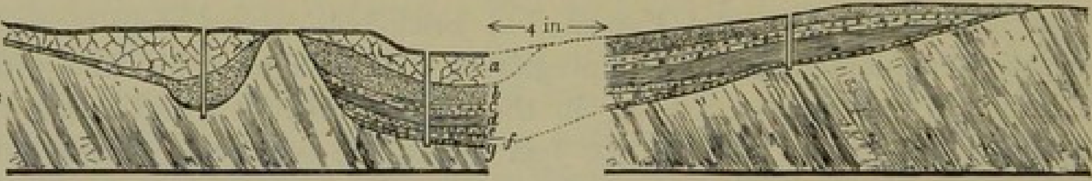

Fig. 231. Section of Auriferous Drift, Ballarat. (Brough Smith.)
a. Basalt. b–g. Drift sands and gravels with gold débris in g. s. Palæozoic Rocks.

Australasia. Local deposits of gravel and clay are widely spread in Australia, and bones of gigantic Marsupials, and in places shells, occur in the Drift-beds. The mining-works in the valleys of Victoria have afforded unrivalled opportunities of ascertaining the former contours of the valleys and the dimensions of these deposits. They consist of beds of sand, gravel, and clay, to the thickness (in round numbers) of from 20 to 400 feet. These deposits (' Leads ') are remarkable for the quantity of trunks and fragments of trees, very little altered, contained in some of the beds. The gravels also are true boulder-gravels; and lava-streams sometimes cover, and at other times are intercalated with, the Drift-beds. The age of these deposits is not, however, yet well defined. Some of the lower beds have been referred to the Miocene, others to the Pliocene or to the Pleistocene, while some seem to be very recent. It is interesting to note the variety of channels ('Leads') formed by the changing régime of the old rivers[1].

But neither in Australia nor in New Zealand have any traces of man been found in these deposits.

North America. The Champlain Period of the American geologists corresponds with that of the Valley-drifts of Europe: that is to say, it was the period during which the great ice-sheet retreated, and the lands, so long wrapt in ice and snow, again became exposed. The melting of the ice, added to the rainfall, gave rise to torrential floods, which subjected the river-channels to rapid wear and exceptional erosion. The phenomena were on a still larger scale in America than in this country. The ice-sheet was more extensive and thicker, and the rivers longer. It would appear, however, that in America, synchronously with the retreat of the ice, the land—which during the Glacial Period had been raised—now underwent a contrary movement, so that the sea encroached on the continent, and extended far up the valleys. Old sea-margins, containing shells of recent species, occur all along the Atlantic coast, increasing in height from 50 feet in Connecticut, to 200 feet in Maine, to 450 feet in parts of Canada, and to 500 feet in Labrador; while they extended inland as far as Lake Ontario. At the same time, the great valley of the Mississippi was filled with sand and gravel (the Orange-sand beds) to the depth, in places, of from 400 to 500 feet. In Arctic America, the difference of level has been estimated at 1000 feet.

Professor J. D. Dana, who considers that the Champlain Period is, as regards the glaciers, a part of the Glacial Period, but as standing apart from it in view of the altered relations of the land and sea and the change of climate, has made some very interesting observations on the consequences following on the melting of the ice in the Connecticut valley[2]. The old river-terraces in this valley are numerous, very perfect, and extend for a distance of 250 miles inland. The river has excavated its valley through a high-level plain to a depth of from 150 to 200 feet, with a width of from one-eighth of a mile to one mile. The mean depth of the river in flood at this geological epoch is estimated by Dana to have been about 140 feet, the mean height of the present floods being about 26 feet. The mean width of the upper section of the flooded stream he estimates at 6000 feet. Taking these measures together with the mean slope, he obtains a maximum velocity of over 12 miles, with a mean of about 3½ miles, per hour, whence some idea may be formed of the enormous transporting power of the river of that period (see Vol. I, p. 83). The annual rainfall in that district now

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[1] See 'Rosales' in 'Quart. Journ. Geol. Soc.,' vol. xv. p. 407, 1859; Selwyn's 'Physical Geography, Geology, etc. of Victoria;' Brough Smyth's 'The Goldfields of Victoria,' etc.

[2] 'Amer. Journ, Sci.,' vol. xxiii, February, March, May 1882.

varies from 65 inches on the coast to 42 inches in the interior; but during this part of the Glacial Period, Dana considers that the special conditions must have occasioned a much more abundant precipitation—probably as high as 120 inches, or greater than in any existing glacial region.

Marine Terraces. The sea-shore terrace or 'beach' on this part of the United-States coast is not high, and the few shells found in it have a southern facies; but in the valley of the St. Lawrence, where the shore-lines are much higher[1], they contain a large number of Foraminifera, Polyzoa, and about sixty Mollusca of northern types. Amongst the latter are,—

Saxicava rugosa, *Linn.* Pl. XVI, fig. 3.	Natica clausa, *Brod. & Sby.* Pl. XVI, fig. 11.
Mytilus edulis, *Linn.*	Trichotropis borealis, *Brod. & Sby*
Tellina Grœnlandica, *Beck.*	Buccinum undatum, *Linn.*
Mya truncata, *Linn.* Pl. XVI, fig. 2.	,, Grœnlandicum, *Chemn.*
Leda Portlandica, *Hitch.*	Trophon clathratum, *Sby.* Pl. XVI, fig. 10.

These are all known boreal or Arctic shells; about half of the discovered species occur in the Pleistocene deposits of Great Britain.

Professor Packard[2] is of opinion that the whole Labrador plateau has been moulded by ice to the height of 2500 feet above the level of the sea, whilst the fiords have been excavated to the depth of 1200 feet. The Leda-clays and Sand-beaches extend from a few feet above the sea-level to heights of from 400 to 500 feet. They contain, together with the shells before named, a larger proportion of forms peculiar to Arctic America, such as—

Cardita borealis, *Conr.*	Bela Americana, *Pack.*
Astarte Banksii, *Leach.*	Fusus Labradorensis, *Pack.*

In these deposits there have also been found remains of the Greenland Seal, the Walrus, the Vermont Whale, and the Bison.

River- and sea-terraces are again numerous on the west coast of North America. There are shell-bearing beds 80 to 100 feet above the sea on the coast of California; and Dr. G. M. Dawson states that, in British Columbia, the sea at the time the Strait-of-Georgia glacier began to diminish must have stood considerably higher in relation to the land than at present; for the glaciated rock-surfaces no sooner appeared from beneath the ice than they were covered by deposits holding marine shells.

The Mammalia of this period in America include—

Elephas primigenius, *Blum.*	Ursus pristinus, *Leidy.*
,, Americanus, *Dekay.*	Cervus tarandus, *Linn.*
Mastodon Americanus, *Cuv.*	Megatherium mirabile, *Leidy.*

together with species of Horse, Lion, Tapir, Ox, Bison, Beaver, etc., but no

[1] Sir J. W. Dawson, 'Canadian Naturalist,' vols. ii. iv. and v.

[2] 'Boston Mem. Soc. Nat. Hist.,' vol. i. p. 210; and Professor Hind in 'Quart. Journ. Geol. Soc.,' vol. xxi. p. 122.

Rhinoceros. The remains are found in river-gravels and in Pleistocene swamps, such as that of the Big-Bone-Lick, Kentucky, in which it is said that the remains of as many as a hundred Mastodons and twenty Elephants, besides Megalonyx, have been dug up. Several very perfect specimens of the great Mastodon have been obtained from similar old marshes in New York, Indiana, and Missouri. 'One magnificent specimen was found in a marsh near Newburg, New York, with its legs bent under the body, and the head thrown up, evidently in the very position in which it was mired. The teeth were still filled with the half-chewed remnants of its food, which consisted of twigs of Spruce, Fir, and other trees; and within the ribs, in the place where the stomach had been, a large quantity of similar material was found[1].'

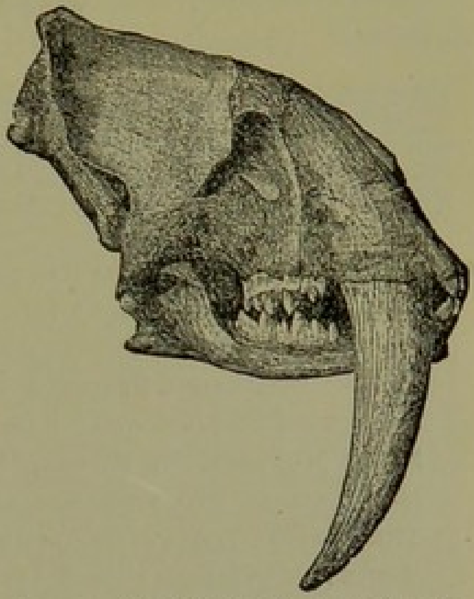

FIG. 232. *Skull of Machairodus*, S. America. From 'Guide to the British Museum.

Flint arrow-heads have been reported to occur with the bones of the Mastodon, and a few instances of human bones associated with some of the river-drifts are recorded; but the evidence respecting the presence of Man in America at this period wants confirmation.

South America. In Brazil and in the Pampas of Buenos Ayres the remains of numerous extinct quadrupeds have been discovered. A noticeable feature is the great preponderance of Edentata, including twelve to fourteen species related to the Megatherium (Sloth), and as many to the Glyptodon (Armadillo), and others to the Megalonyx. Species of Horse, Tapir, Lama, Deer, Mastodon, etc. are likewise found. The remains of the remarkable extinct animal, the *Machairodus*, with its enormous canine sabre-teeth (Fig. 232), have also been met with in the Pleistocene deposits of South America.

Shells are of very rare occurrence in the Pampas mud. Darwin mentions, however, a few instances, the most marked of which is afforded by a section on the coast at Punta Alta in Bahia Blanca, where he found twenty species of recent shells associated with the typical extinct Mammalia of the Pampas deposit. Amongst them were *Paludestrina Australis*, D'Orb., *Cardita Patagonica*, D'Orb., *Voluta Brasiliensis*, D'Orb., etc.,—all species now living on the coast.

[1] Le Conte's 'Elements of Geology,' p. 568.

CHAPTER XXXI.

THE QUATERNARY PERIOD (*continued*).

OSSIFEROUS CAVES.

ORIGIN OF CAVES. CLAPHAM CAVE. BONE-CAVES IN ENGLAND AND WALES: KIRKDALE: PAVILAND: BACON HOLE: MINCHIN HOLE: BOSCO'S DEN: KENT'S HOLE: BRIXHAM CAVE: THE MENDIP HILLS: CRESWELL CRAGS: VICTORIA CAVE, SETTLE. THE CEFN CAVES. OSSIFEROUS BRECCIA: WIRKSWORTH: ORESTON. LIST OF THE CAVE FAUNA. FRANCE: THE BOULONNAIS: OSSIFEROUS BRECCIAS OF THE PARIS BASIN: BURGUNDY: NICE: MENTONE. A HYÆNAS' DEN. A BEARS' DEN. CENTRAL FRANCE: THE DORDOGNE CAVES AND ROCK-SHELTERS OF EARLY MAN. THEIR IMPLEMENTS AND FOOD. THE MAMMALIAN FAUNA. THE BIRDS. BELGIUM: CAVES OF THE VALLEYS OF THE MEUSE; MONTAIGLE; AND LESSE. GERMANY. RUSSIA. THE SOUTH OF EUROPE. SPAIN. GIBRALTAR: OSSIFEROUS BRECCIA. SICILY: MALTA: PIGMY ELEPHANT. FORMER LAND CONNECTION BETWEEN AFRICA AND EUROPE. INDIA. AUSTRALIA. NORTH AMERICA. BRAZIL.

ALTHOUGH we place the caves in a separate chapter, they are, as a rule, synchronous with the valley-drifts. They, however, engaged the attention of geologists before the latter; Buckland [1], in 1823, Marcel de Serres [2], in 1836, Desnoyers [3], in 1849, Dr. Falconer [4], in 1858, and Professor Boyd Dawkins [5], in 1874, have written largely on the general subject.

Origin of Caves. The greater number of caves have their origin in fissures and galleries formed in limestones by the long percolation and passage of water. Some are of enormous magnitude, extending for miles underground and widening into large chambers. Most of these old water-channels are now dry, and were dry at the time of their occupation: others are still water-courses. To take one instance. At Clapham, in Yorkshire, a village situate at the base of hills of Carboniferous Limestone, a little stream issues at the foot of the hill through an opening in the lime-rock. This is the mouth of a narrow gallery, which may be followed under the hill for a distance of nearly the third of a mile, and through which the small stream issues, charged with the carbonate of lime taken up in its course. The passage, the bottom of which is covered with sand and

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[1] 'Reliquiæ Diluvianæ.'
[2] 'Essai sur les Cavernes à Ossements.
[3] Article 'Grottes' in Ch. D'Orbigny's 'Dictionnaire Univ. d'Hist. Nat.'
[4] 'Palæontological Memoirs.'
[5] 'Cave Hunting.

pebbles, becomes too narrow to be followed further. But higher up the hill, and within the distance of a mile, there are various swallow-holes into which the surface-waters run; and at one spot a break through the rock exposes one of these underground streams falling over a ledge and lost again in the rocks beneath (Fig. 233).

In limestones the innumerable fissures, joints, and planes of bedding are the channels through which the surface-waters find a passage. Small at first (see plan of Brixham Cave, p. 492), they are gradually worn larger by the acidulated waters, until sometimes so enlarged that the relation of the galleries to the fissures is not readily apparent. As a consequence of this action, the limestone hills in all countries are often riddled by such water-passages of various and very different dates and sizes; but in most cases the entrances are hidden and blocked up by soil and débris. Many were in early times the resorts of the wild animals, and at later times of man.

FIG. 233. *View of Underground Watercourse (Weathercote Cave), Ingleborough Hill.* (Phillips.)

Bone-Caves. Kirkdale Cave, near Pickering, in **Yorkshire**, was explored by Buckland in 1821. It is near the top of a low hill, and about 80 feet above the level of the river. The cave, which is only two to four feet high, three to six feet wide, and 245 feet long, has several branches. A layer of red loam, one to two feet thick, covered the bottom of the cave; and at the further end this was coated with stalagmite. The bones were very much broken and almost all were gnawed. Amongst the remains were those of between 200 and 300 Hyænas. Their accumulated coprolites and teeth, belonging to animals of all ages, show that this den was long their habitual resort. Mixed with these were the bones of the animals on which the Hyænas fed, consisting chiefly of Bison, Horse, Reindeer, Megaceros, and more rarely Elephant, Rhinoceros, etc. The great interest of this cave was in the demonstration, by Buckland, of the exact analogy afforded of the mode of feeding and habits of the Hyæna to those of the present day[1].

[1] In some districts of North Africa there are at present numerous Hyæna dens of a similar character (with in addition human bones and skulls).

Another group of caves to which Buckland directed his attention are those in the Carboniferous Limestone cliffs and hills of **South Wales**, especially those of Gower, which were afterwards more thoroughly examined by Colonel Wood, of Stout Hall, and Dr. Falconer. These caves, to the number of eleven or twelve, open out on the face of the cliffs at a height of 20 to 30 feet above the sea, and are difficult of approach.

In Paviland Cave Dr. Buckland discovered the skull of a Mammoth with the tusks nearly entire, together with the remains of Horse, Bear, Hyæna, etc. There was also found, at a short distance from the skull, the skeleton of a man (though first known as the 'red lady of Paviland') nearly entire, stained with red ochre, and accompanied by some thick ivory pins and rings. The cave had been greatly disturbed; and Dr. Buckland concluded, from this and other reasons, that the skeleton was of prehistoric, but not of geologic times. At that time, however, the contemporaneity of Man with extinct animals was supposed to be an impossibility.

Bacon Hole contained, with other bones, a great number of those of the *Rhinoceros hemitœchus*, a species comparatively rare in England; eleven molars and a fragment of a large tusk of *Elephas antiquus*, together with the remains of Hyæna, Wolf, Bear, Ox, Deer; the bones being mostly entire, and showing no trace of gnawing. Neither *E. primigenius* nor *R. tichorhinus* occurred in this cave, at the bottom of which was a bed of sand with marine shells of recent species.

In Minchin Hole the conditions were very similar to those in Bacon Hole, and the organic remains analogous. Two fine entire skulls of *Rhinoceros hemitœchus* were found in the marine sand at bottom. The Hyæna does not seem to have inhabited either of these so-called caves, both of which are connected with the surface by fissures, and contained much bone-breccia.

Bosco's Den is stated by Dr. Falconer to belong to another order of caverns, in which the bones have been washed in from the surface. It consisted of an upper and lower chamber, separated by a thick mass of bone-breccia. In the lower chamber sand and gravel only were found. In the upper chamber the floor of stalagmite and breccia was covered by a layer of peaty sand, in which there were an innumerable quantity of bones of Ox, Wolf, and Reindeer. No bones of Horse, Elephant, Rhinoceros, or of Hyæna were found in this cave, which was remarkable for the singular abundance of the shed antlers of the Reindeer, or of a species closely allied to it (*Cervus Guettardi*). Colonel Wood counted no fewer than 1100 specimens, of which 95 per cent. had the base of the beam and burr perfect. They were of small size and more or less broken, and belonged mostly to young animals. Some were much rolled. It is probable that this cave, together with Bowen's Parlour and several other of the Gower Caves, although classed with caves, are really fissures, partly open and partly filled with ossiferous breccias; and that the antlers had been shed by deer among the bushes on the banks of the streams running into the fissures and so got washed in.

Devonshire: Kent's Hole. This cave, close to Torquay, has a wide open entrance and is the largest of the English bone-caves. Within the last twenty years it has been thoroughly explored under the able superintendence of Mr. Pengelly. His series of fifteen Annual Reports form a valuable record of systematic cave-work[1]. The cave had been frequented from Quaternary to Historic times, so that, while the cave-earth and breccia below the stalagmite contain the remains of Pleistocene Mammalia, with

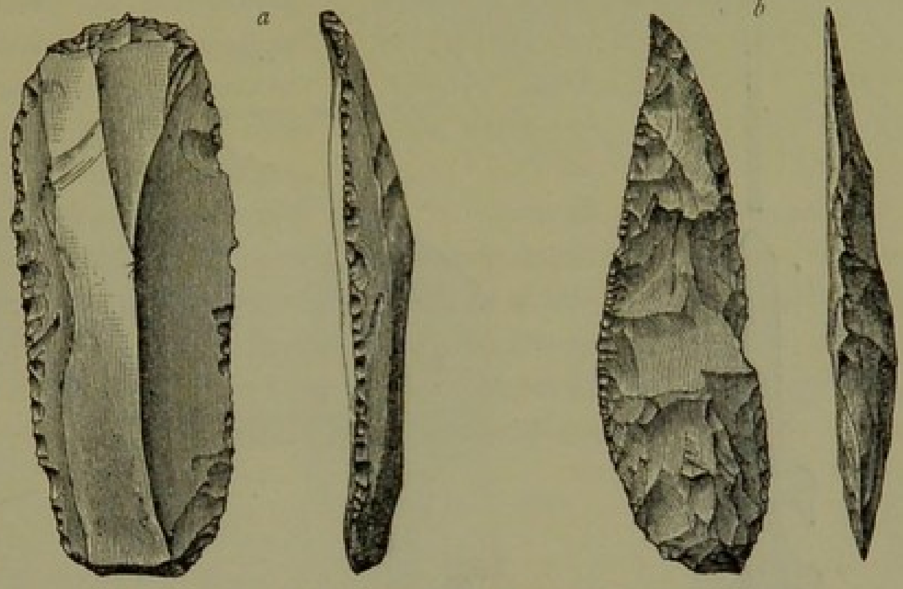

FIG. 234. Flint Implements from Kent's Cavern, Torquay. (Evans.)
a. Scrapers, nat. size. *b. Pointed Flake*, ½ size.
Besides these are others of the larger ordinary pointed and ovoid palæolithic type.

implements of Palæolithic Man, the soil above this contains the remains of existing animals and of Neolithic Man, succeeded by Roman and Mediæval remains. In the basement breccia the remains of Bears largely predominate: this was at first covered over by a layer of stalagmite, in some places twelve inches thick, which was broken up by some external cause, and then succeeded by the cave-earth, with angular rock fragments. To this latter bed the bones, teeth, and coprolites of Hyæna are almost, if not entirely confined, while the remains of Bears are here comparatively scarce. The cave thus appears to have been at first a den of Bears, and afterwards of Hyænas. A few teeth of the formidable Machairodus have been found in this cave. The other animals

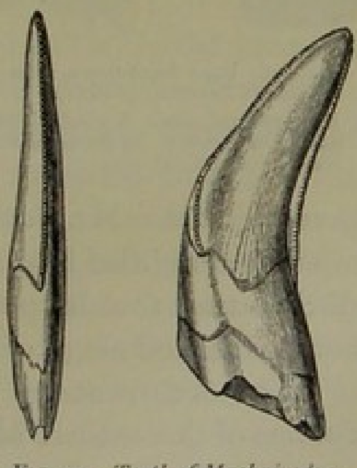

FIG. 235. *Tooth of Machairodus latidens*, Owen, ½.

[1] 'Brit. Assoc. Reports,' 1865–79.

were brought in as prey. The distribution of their remains in the different chambers was very irregular. In his Eighth Report, Mr. Pengelly states that the per-centages of the teeth found in the cave-earth in one of the chambers was as under:—

	Hyæna.	Horse.	Rhinoceros.	Megaceros.	Bear.	Deer.	Elephant.	Ox.	Wolf.	Lion.	Fox.	Rabbit.
Total per cent.	44	25	15	3	3	2.5	2.5	1	1	1	1	0.5

This will give a general idea of the relative proportion of the different

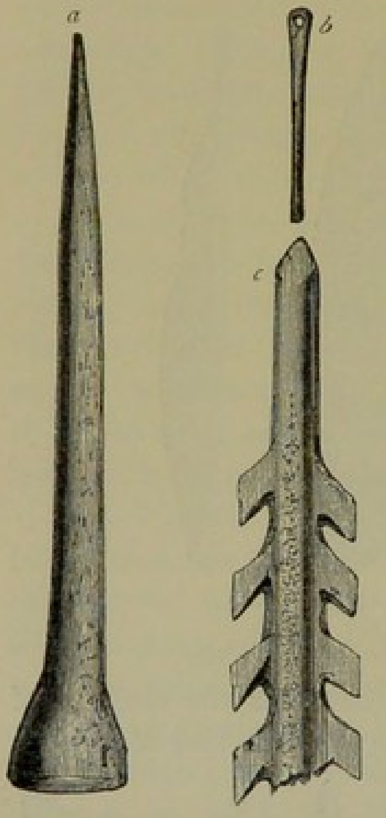

FIG. 236. Bone Implements from Kent's Cavern. (Evans.)
a. Bone pin, nat. size. *b. End of Bone needle*, nat. size. *c. Broken Bone, Harpoon-head*, nat. size.

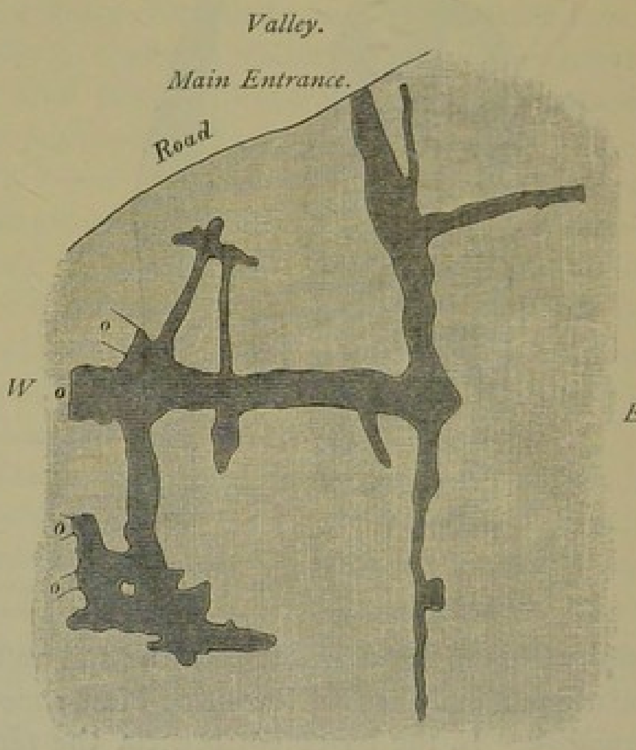

FIG. 237. Plan of Brixham Cave.
o. Various small openings to surface.

Cave animals. Mr. Pengelly also found that the greater number of the flint implements in the lower breccia were ruder than those of the cave-earth, in which latter the harpoon and other bone objects, Fig. 236, showing a more advanced stage of art, were found.

The occurrence of these worked implements, in association with the remains of the extinct Mammalia, had been noticed by M^cEnery in 1825–40, subsequently by Godwin-Austen in 1840, and more carefully investigated by a local committee in 1846; but their statements had been looked upon with incredulity by geologists until confirmed by the discoveries in the new and undisturbed cave at Brixham, and elsewhere. Full particulars of these and the other cave implements will be found in Dr. Evans's work before cited.

Brixham Cave. This cave, discovered by chance in 1858, was until then hermetically sealed up by a talus of limestone breccia (2), and had never been entered nor disturbed. The cave being small, it was possible to empty it entirely of its contents; and, as everything passed through the hands of Mr. Pengelly, by whom the exact position of every specimen was noted, we have in this case the complete record of an ossiferous cave of Quaternary date.

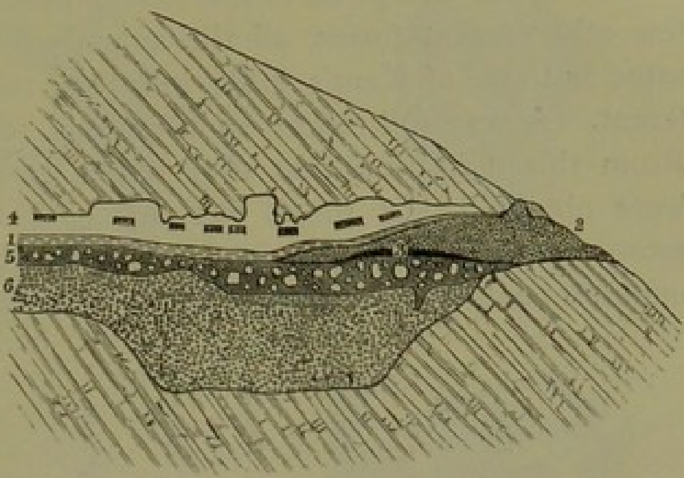

FIG. 238. *Section of Brixham Cave.*

The cave is situated on the brow of a hill of Devonian Limestone, at a height of 66 feet above the level of the stream in the valley below, and 94 feet above the sea, from which it is about half a mile distant. The succession of beds is shown in the following section :—

1. Stalagmite with a few bones and antlers of Reindeer	0 to 15 inches.
2. Angular débris fallen from above	0 to 10 feet.
3. Black peaty bed	0 to 1 foot.
4. Remnants (in sitû) of an old Stalagmitic floor	6 to 12 inches.
5. Red Cave-earth with angular fragments of limestone, numerous bones, and some worked flints	3 to 4 feet.
6. Shingle, consisting of pebbles of limestone, slate, and other local rocks, with fragments of the old stalagmite and a few bones and worked flints	5 to 16 feet.

A noticeable feature, but occurring also in other caves, is the presence of patches or ledges of an old stalagmitic floor (4) three to four feet above the present floor, and six to twelve inches thick adhering to the walls and roof of the cave. On its under side there are often attached fragments of limestone and quartz, showing that bed No. 6 once extended up to it, and that it then formed an original floor. The shingle therefore once stood some feet higher than it does now, and nearly filled the cave. We have to suppose that a shock or jar, such as that of an earthquake movement, broke up this original floor, fragments of which are found in the shingle-bed beneath; and that the mass of underlying pebbles, forming bed No. 6, sunk deeper in the fissures and became readjusted, like corn shaken in a sack, into a smaller space, and so rendered the cave larger than before. The space thus gained was afterwards only partially filled up by the Cave-Earth No. 5. At a later period the fall of angular fragments (2) at the entrance finally blocked up the cave, and it ceased to be accessible except to a few burrowing animals, whose remains were found above the second and newer stalagmitic floor.

With the exception of the Machairodus, Irish Deer, Wild Boar, and a few other recent forms, all the animals from the Brixham Cave are the same as those of Kent's Hole, but their relative proportions are very different. A very full report on them was made by the late Mr. G. Busk[1]. From this it appears that 1621 bones, mostly in fragments and gnawed, were obtained. Of these, 691 belonged to birds, small rodents, etc. of more recent times, and were found above the stalagmite, while 261 were undeterminable. The remaining 669 were divisible as under:—

Bear.	Deer.	Rhinoceros.	Hyæna.	Horse.	Ox.	Fox.	Elephant.	Lion.	Lemming.
354	97	67	57	30	28	15	11	9	1

With the bones there were found thirty-six flint flakes and flint-implements—nineteen in the cave-earth (5) and seventeen in the shingle (6). A curious point in connection with them is that one large, rude, pointed implement was found in two pieces, at three and three and a-half feet depth in the cave-earth, the butt end being in one gallery and the point in another 44 feet distant.

We may conclude from these structural and palæontological facts, that the formation of the cave commenced and was carried on simultaneously with the excavation of the valley—that the small streams flowing down the upper tributary branches of the valley entered the western openings of the cave, and, traversing the fissures in the limestone, escaped by lower openings in the chief valley; and that those streams brought in the shingle-bed, No. 6, which fills the bottom of the cave. It was only during occasional droughts, when the streams were dry, that the cave then seems to have been frequented by animals, their remains being very scarce in the shingle; while remains of Man's works were relatively more numerous. As the excavation of the valley proceeded, the level of the stream was lowered and diverted, and the cave consequently became drier, and was more resorted to by predatory animals bringing in their prey to devour; while at the same time the gradual accumulation of the cave-earth, carried in after rains, buried the bones left from season to season by succeeding generations of beasts of prey. During this time the occasional visits of Man are indicated by the rare occurrence of a flint implement, lost probably as he groped his way through the dark passages of the cave. At last the cave seems to have become a permanent resort for bears: for their remains in all stages

[1] 'Trans. Royal Soc.' for 1872, p. 499.

of growth, including even sucking cubs, were met with in the upper part of the cave-earth, in greater numbers than were the bones of any other animal.

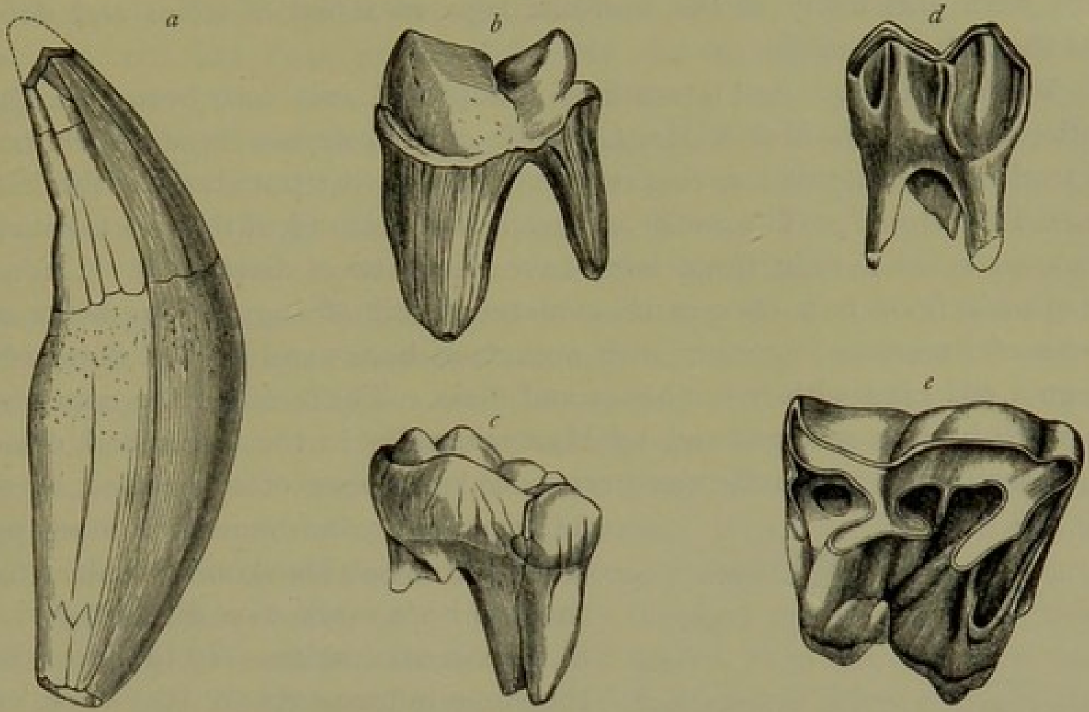

FIG. 239. Teeth of various Cave Animals, $\frac{3}{4}$ nat. size.
a. Canine of Lion. b. Molar of Hyæna. c. Molar of Bear. d. Molar of Reindeer. e. Crown of tooth of Rhinoceros hemitæchus, Falc.

The Mendip Hills. This Carboniferous Limestone range is another great cave centre, from which large collections were made by the Rev. D. Williams and Mr. Beard. In Banwell and Burrington Caves they found that Bears predominated. Hyænas seem not to have been numerous, for few bones had been gnawed by them; but it is necessary to remark that many of the so-called caves are, as in Gower, not true caves, but fissures filled in from above with ossiferous breccia. The other animals (see list, Bleadon Cave, p. 498) are of the same species as those of South Wales, though the Mendip cave-fauna was further characterised, according to Professor B. Dawkins, by the great proportion of Lions.

Wookey Hole, near Wells, explored by Boyd Dawkins[1], presents also another instance of a den frequented by Hyænas. The cave is situated in the dolomitic conglomerate of the Trias. It was filled with débris to the very roof. Bones and teeth of the various cave animals were found in the greatest abundance, the bones being smashed, splintered, and scored with tooth-marks of the Hyæna, whose remains largely preponderated. Thus, of Hyæna teeth, there were 467, of Horse 401, of Rhinoceros 235, of Deer 67, of Bear 49, of Ox 46, of Mammoth 30, of Cave-Lion 15, of

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[1] 'Quart. Journ. Geol. Soc.' for 1862 and 1863; and 'Cave Hunting,' p. 295.

Fox 8, of Wolf 7, and of Lemming 1. Those of the Mammoth were all of young animals.

A considerable number (35) of palæolithic flint implements were found; there were also many of the neolithic type in a bed of ashes and débris near the entrance of the cave.

Derbyshire. An interesting group of Caves has been described by the Rev. J. M. Mello, Mr. G. Busk, and Professor Boyd Dawkins in Creswell Crags, a small ravine running through compact beds of the Magnesian Limestone[1]. The rocks are much fissured, and in the short distance of a quarter of a mile three bone-caves have been discovered. Under a stalagmitic floor is a cave-earth, sometimes full of angular fragments and blocks of limestone, together with numerous bones and worked flints, resting on a red sand with fewer bones and flints. The bones in the upper bed are much broken and gnawed by Hyænas, while in the lower bed, during the deposition of which the cave seems to have been often flooded by the adjacent river, the bones are more perfect. Professor Dawkins considers that the two beds mark two distinct periods of human occupation. In the lower bed the stone implements are very rude, and many of them are made of quartzite pebbles obtained from the adjacent Triassic conglomerate; whereas in the upper bed both large pointed and better finished forms of implements of flint foreign to the district occur, together with bone implements, such as needle and awls made of the tynes of antlers. A deer's rib incised with a rude figure of the head of a hog-maned horse (Fig. 240), is, I believe, the only drawing yet found in the caves of this country.

Fig. 240. *Etching of Head of Horse on bone, Creswell Caves, Derbyshire.* (After Professor B. Dawkins's sketch.)

In these caves the Machairodus hitherto confined to Kent's Hole was also found, together with Glutton and Leopard, which occur in the Mendip caves. The other animals are of the usual cave type (p. 498). In one of these Caves (Robin-Hood), 2588 bones and 1032 chips and fashioned flints were obtained from the cave-earth and breccia, while only 148 bones and 8 flints were found in the lower bed. Some of the flints of the upper bed are of the Moustier type (see p. 505). In the same bed were also found pieces of ruddle, used possibly for paint.

The soil on the surface of the stalagmite contained bones of Ox (*Bos longifrons*), Goat, Pig, and Dog, with fragments of Samian ware, etc., showing that the cave was frequented through Roman down to later times.

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[1] 'Quart. Journ. Geol. Soc.' for 1875, 1876, 1877.

The Hills of West Yorkshire. The range of the Carboniferous Limestone, that extends from Derbyshire to Yorkshire, is honeycombed by caves and fissures, only a few of which have been examined. The most northern cave described is Victoria Cave near Settle. It is 1450 feet above sea-level, and has been explored by Mr. R. H. Tiddeman, from whose Reports[1] we gather that inside the cave there are: 1st. An upper cave-earth with large and small angular blocks of limestone and pieces of stalactite fallen from the roof. This bed, from two to ten feet thick, contains remains of Bear, Reindeer, Badger, Horse, Fox, and Wild Boar. Some of the bones are hacked. 2nd. An irregular bed of very finely laminated grey clay, which thickens inwards to a depth of 12 feet; it has a few thin subordinate seams of stalagmite, but not a trace of any organic remains. 3rd. Another and thicker bed of cave-earth, with angular limestone fragments, at the base of which were found remains of *Elephas antiquus, Rhinoceros hemitœchus*, Hippopotamus, Bear, Bison, Hyæna, etc., together with numerous coprolites of Hyæna. It was in this bed also that was found the fibula which has been dubiously assigned to Man or Bear.

The entrance to the cave was partly blocked up by a talus of débris fallen from the weathered limestone cliff above. On the top of it was a dark layer with burnt bones, fragments of Samian and other pottery, coins, etc. Beneath this Romano-British layer, a bone harpoon and some flint flakes of Neolithic age were found. At the base of and under the great mass of talus, and resting at a considerable angle on the edges of the inside cave-beds, were a number of erratic blocks of the same character as those occurring in the glacial beds spread generally over the district.

Mr. Tiddeman concludes that the lower cave-earth (3) is of Pre-glacial age—that the laminated clay was washed in from the outside boulder-clay during the Glacial Period—and that the upper cave-earth only is Post-glacial. During the first period, the cave was the resort of Hyænas, and during the latter of Bears.

North Wales. On stratigraphical grounds, Mr. Mackintosh referred the Cefn caves to an Interglacial period. On new and fuller evidence furnished by two caves in the Vale of Clywd, Dr. Hicks has recently arrived at the conclusion that they are Pre-glacial. *Elephas antiquus* and *Rhinoceros hemitœchus*, Glutton, and Hippopotamus, and with them a flint flake, have been found in these caves; while in Pontnewydd cave, near Cefn, Professor McKenny Hughes has discovered rude implements of felsite, flint, and chert, associated with the Mammalian remains.

Amongst the specimens from these Welsh caves sent to Mr. Busk was a human molar tooth of very large size, exceeding in this respect any with which he compared it, except one or two from Australia or Tasmania.

[1] 'British Association Reports,' 1873–75.

This and the fibula from Victoria Cave are the only two recorded instances of the supposed occurrence of human bones in British caves.

Prof. M^cKenny Hughes and other geologists give, however, a different interpretation to the phenomena, and contend that both these caves, as well as the Victoria Cave, are of Post-glacial and not of Pre-glacial age. There is certainly little or nothing in the distribution of the Fauna alone in the English and Welsh caves to indicate any material difference of age, as the following list will show.

THE CAVE-FAUNA OF ENGLAND AND WALES.

The extinct species are marked with an asterisk; the others are existing species.			1. Kent's Cave, Devon.	2. Bleadon, Somerset.	3. Spritsail Tor, Gower.	4. Wookey Hole, Somerset.	5. Creswell-Crags Caves.	6. Kirkdale, Yorkshire.	7. Victoria Cave, Settle.	8. Cefn Caves, North Wales.
Ungulata.	Rhinoceros tichorhinus*	Woolly Rhinoceros	—	...	—	—	—	...	...	—
	,, hemitœchus*		...	...	...	—	...	—	—	—
	Equus caballus	Horse	—	—	—	—	—	—	—	—
	Sus scrofa	Wild Boar	—	—	—	—	—	—	—	—
	Hippopotamus major*	Hippopotamus	?	...	...	...	...	—	—	—
Ruminantia.	Cervus elaphus	Red Deer	—	—	—	—	...	—	—	—
	,, capreolus	Roebuck	...	—	—	...	...	...	...	...
	,, tarandus	Reindeer	—	—	—	—	—	—	—	—
	,, megaceros*	Irish Deer	—	—	—	—	—	—	...	—
	Bison Europæus	Bison	?	—	—	—	—	—	—	—
	Bos primigenius	Urus	—	—	...	—	—	...	...	...
Proboscidea.	Elephas primigenius*	Mammoth	—	—	—	—	—	...	...	...
	,, antiquus*		...	—	—	...	?	—	—	—
Rodentia.	Lepus timidus	Hare	—	...		—	—	—	...	...
	,, diluvianus		...	...	...	—	...	...	...	...
	Lagomys pusillus	Tailless Hare	—	—	...	...	...	...	...	...
	Myodes lemmus	Lemming	...	—	...	—	...	...	...	...
	Castor fiber	Beaver	—	...	...	...	...	...	...	...
	Sphermophilus citillus	Pouched Marmot	...	...	...	—	...	...	...	...
	Arvicola amphibia	Water Vole	...	...	...	...	—	...	...	...
Carnivora.	Ursus spelæus*	Cave Bear	—	—	—	—	...	—	...	—
	,, arctos	Brown Bear	—	—	—	—	—	—	—	...
	,, ferox	Grisly Bear	—	...	—	—	—	—	—	—
	Meles taxus	Badger	...	...	...	...	...	...	—	...
	Lutra vulgaris	Otter	—	—	...	...	...	...	...	...
	Gulo borealis	Glutton	...	—	...	...	—	...	...	—
	Canis lupus	Wolf	—	—	...	—	—	—	—	—
	,, vulpes	Fox	—	—	...	—	—	—	—	—
	,, lagopus	Arctic Fox	...	...	...	...	—	...	...	...
	Mustela martes	Marten	..	—	—	...	...	...	...	...
	,, erminea	Stoat	—	...	...	...	...	—	...	...
	,, putorius	Pole Cat	...	...	—	...	—	...	...	...
	Felis spelæa*	Cave-Lion	—	—	—	—	—	—	...	—
	,, pardus	Leopard	...	—	...	...	—	...	...	...
	,, catus	Wild Cat	—	—	...	...	—	...	...	...
	Machairodus latidens*		—	...	...	...	—	...	...	...
	Hyæna spelæa	Spotted Hyæna	—	—	—	—	—	—	—	—
	Stone Implements, the work of	Man	—	...	...	—	—	...	—	—

Ireland. The fauna of the Drift and Caves deposits of Ireland differ very considerably from those of England. The Pre-glacial fauna is marine, while the Post-glacial land presents a fresh-water fauna of much less variety than in this country. The Mammoth, three species of Bear, Ox, Deer, and Wild Boar existed, but large Carnivora were absent. Neither the Hyæna, Lion, nor Leopard have been met with. On the other hand, owing, no doubt, as Professor Hull suggests, to the absence of these predaceous animals, Deer flourished to an extraordinary extent. Besides the Red Deer and Reindeer, the Irish Deer (*Cervus megaceros*) abounded. Its remains, often entire, with its noble antlers (7 to 8 ft. from tip to tip), are common in and at the top of the gravel lying at the base of many of the peat-bogs. Nowhere else is it found in such profusion.

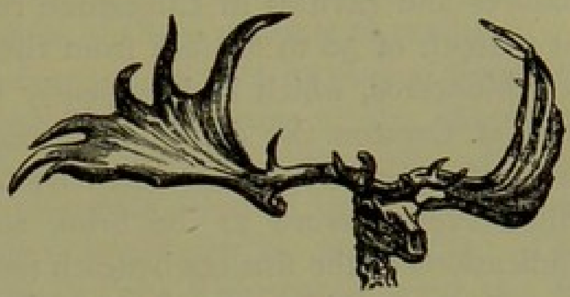


FIG. 241. *Head of Megaceros giganteus.*

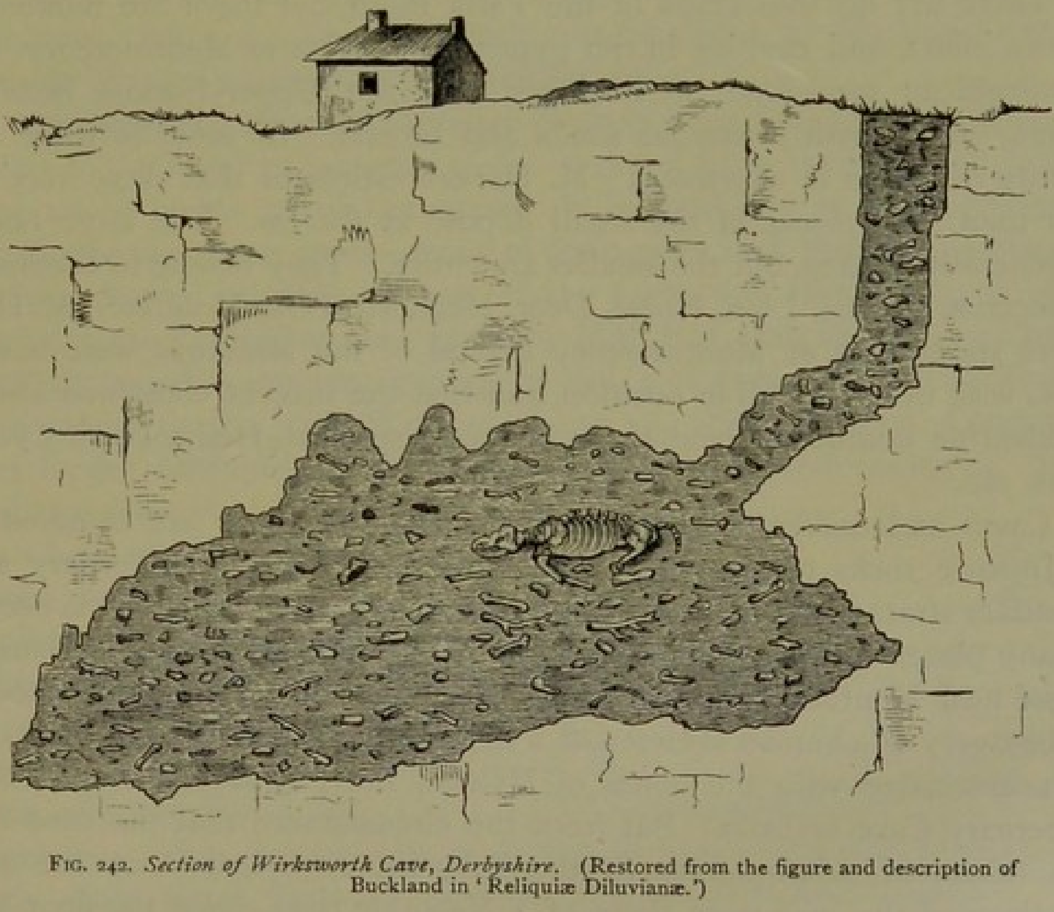


FIG. 242. *Section of Wirksworth Cave, Derbyshire.* (Restored from the figure and description of Buckland in 'Reliquiæ Diluvianæ.')

Ossiferous Breccias. These contain remains of almost equal importance with the Caves with which they have been often confounded. Instead, however, of the remains being those of animals brought into the Caves by the animals which frequented them, they are those of animals which from time to time fell into those natural pit-falls or traps, or else are bones which were washed in from the surface. Wirksworth in Derbyshire, and Oreston in Devonshire, are typical cases of Ossiferous Breccias filling fissures and cavities in Limestone rocks. In the former, Buckland found, at a depth of 50 to 60 feet from the surface, the nearly entire skeleton of a Rhinoceros, which had evidently fallen in and died there. Both there and at Oreston the débris had been washed in from the top; and this, with the rock fragments fallen from the sides and roofs, had completely filled every fissure to the brim, so that the ground above showed no indications of the fissures beneath (see Fig. 242).

France. Two small caves in the Carboniferous Limestone of the Boulonnais, about 60 to 70 feet above the level of the adjacent stream, have been described. A feature of one of these caves was that the cave-breccia with Reindeer, Roebuck, and Horse, was overlain by a bed of loam containing fluviatile shells.

There are no true caves in the Paris Basin, but there are numerous fissures, joints, and cavities in the gypsiferous strata of Montmorency, the Fontainebleau sandstone of Etampes, and the Upper-Eocene beds of Auvers,—filled with ossiferous sands and breccia. In some of these the quantity of bones is enormous. M. Hébert estimates that there were no fewer than 5000 pieces in the small deposit at Auvers. The large bones are generally broken, but the smaller are entire. They belong to Elephant, Rhinoceros, Hyæna, Lion, Horse, Deer, Megaceros, Ox, Mole, etc. M. Desnoyers states that at Montmorency several of the skeletons were nearly entire, with the bones all in position, and that the breccia contained also a considerable number of land shells of recent species—Helix, Pupa, Cyclostoma, etc.

Caves and ossiferous breccias of a similar character are common in the Jurassic rocks of Burgundy and Charente, and in the Tertiary and Secondary strata of the Southern Departments of France. The breccia occurs in many places in the neighbourhood of Nice. The open cave of Baussé-Raussé near Mentone became celebrated a few years ago in consequence of the discovery of a human skeleton at a depth of some seven feet in the cave-earth, associated with the bones of Hyæna, Bear, Rhinoceros, and other Quaternary Cave animals. But from the circumstance that the cave had been inhabited subsequently to the Palæolithic period,—that the surroundings of the man were those of a Neolithic type,—that the floor had been often disturbed, the geological evidence appears inconclusive, and the Palæolithic age of the skeleton cannot be regarded as established, although there can be no doubt of its high antiquity and its great interest on other grounds.

The cave of Lunel-Vieil near Montpellier is a good example of a Hyænas' den, and that of Lherm, near Foix, of a Bears' den. At Lunel-

Vieil the animals were of the same species as those of the English caves, with the addition of the Striped Hyæna and the Caffir Cat of Africa, neither of which are met with in England. The Reindeer and Roebuck were absent. In all there were thirty-three species. The bones had been gnawed by Hyænas, as at Kirkdale, and coprolites of those animals abounded.

The 'Grotte de Lherm' is a magnificent bone-cave, its several branches extending for a distance of about 2000 feet, and some of the chambers being of great width and height. A grey powdery cave-earth, with innumerable bones and angular rock-fragments, spreads over the floor of the cave, and it is only in places that it is covered by stalagmite. The bones are those of the usual cave animals; the Rhinoceros being the *R. tichorhinus*, and the Hyæna the *H. spelæa*. With these are associated the Reindeer and the Aurochs. The remarkable feature of this cave is the extraordinary abundance of the entire skulls and skeletons of Bears, a number of which—thanks to the persevering labours of Dr. Noulet, who described the cave in 1874—are now mounted and exhibited in the Toulouse Museum. After the Bear this cave was inhabited by Neolithic and Prehistoric Man, of whom there are plentiful relics.

In Central France there are caves of later date and special interest, owing to the frequent presence of the works of early man and the evidence they afford of his gradual progress. It is especially in Périgord and the Dordogne that these caves—many of them mere rock-shelters—particularly occur. A very valuable account of the caves and their contents on the banks of the Vézère has been given by MM. E. Lartet and Henry Christy[1], assisted by other eminent geologists and biologists. The river flows for a distance (as the crow flies) of about 14 miles, between Condat and Les Eyzies, through a deep valley excavated in Cretaceous rocks. In this distance some nine caves have been explored. The strata consist of compact limestones, alternating with soft and friable calcareous sandstones and freestones. These strata have weathered very irregularly; the harder beds often form over-

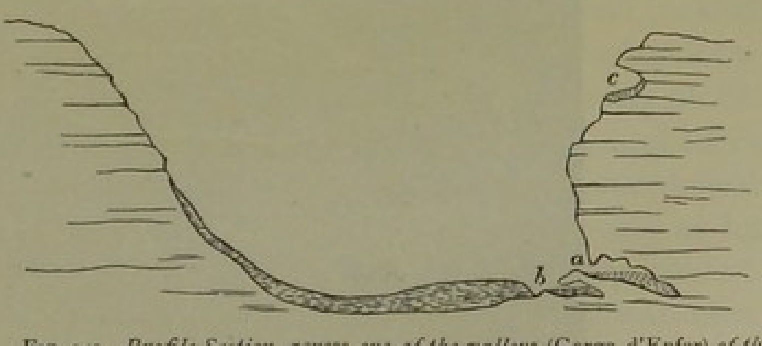


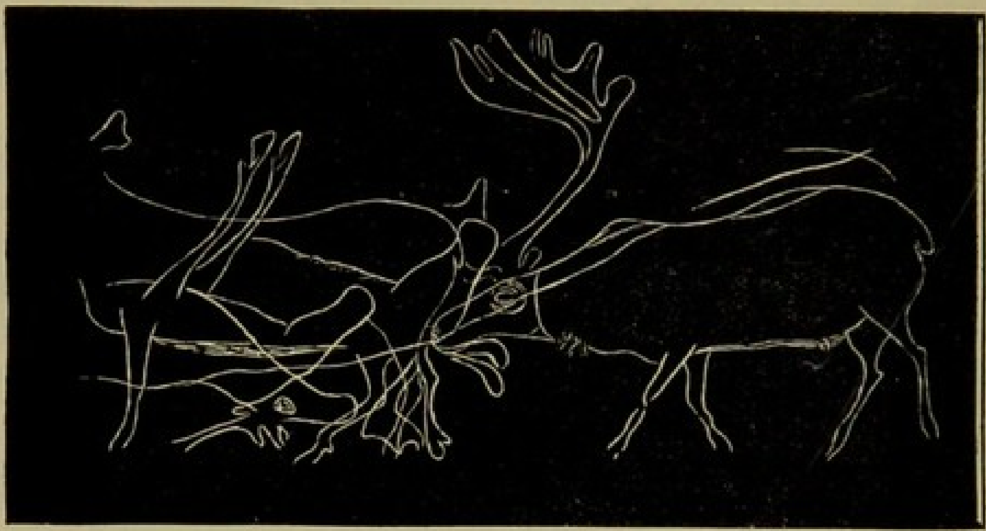
FIG. 243. *Profile-Section across one of the valleys* (Gorge d'Enfer) *of the Dordogne, showing generally the position of the caves* (*a*, *b*) *and rock-shelters* (*c*). (After a sketch in the Reliquiæ Aquitanicæ.)

hanging ledges of rock, and are at times tunnelled by old water-courses, while the softer beds are worn at all levels into cavities which could be easily enlarged. Consequently, it was a locality peculiarly well adapted to a cave-dwelling people, attracted probably by the abundance of game on the wooded heights, and of fish in the rivers.

[1] 'Reliquiæ Aquitanicæ,' 1875. A posthumous work, edited by Professor Rupert Jones, F.R.S.

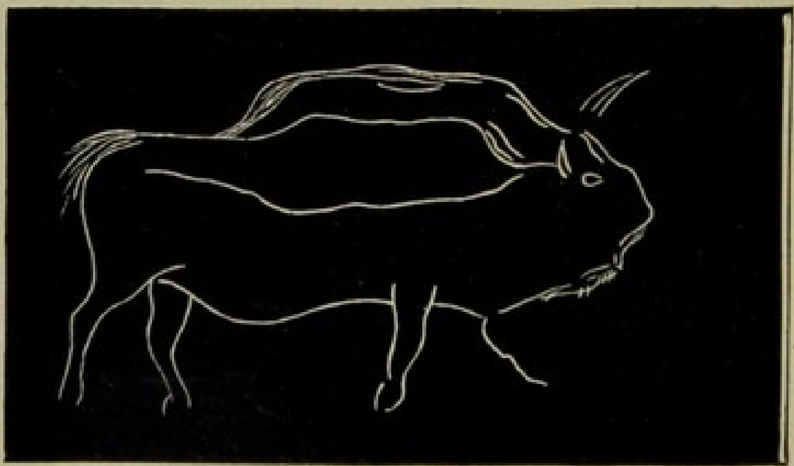
In England and Wales the caves were in the first place the dens of wild beasts, and were only occasionally visited by Palæolithic man; but in this and many other parts of France they were more often the habitation solely of early man; and the fauna of the country is known not from its introduction into the caves by the wild animals, but by the hands of Man.

FIG. 244. Etchings on a slab of slate (½ size) from the Bone-cave of Les Eyzies, Dordogne.



a. Reindeer fighting. This is on one side of the slab. (From a Photograph.)

M. Lartet states that neither in the caves of Les Eyzies and Moustier, nor in the three rock-shelters of La Madelaine and the two Laugeries, have any gnawed bones been found, with one solitary exception. Hence he supposed that the people, who congregated in these caverns and rock-shelters,



b. Figure of Aurochs on the reverse of the same slab.

must have closed them up to prevent the access of the many predatory animals of which the remains exist in the different locations. M. Lartet[1] also supposes that the larger animals were cut up on the spot where they were

[1] *Op. cit.*, chapter i.

killed, and only the extremities, with their fleshy parts and marrow-bones and heads, were carried away to the caves. The smaller animals, especially the Reindeer, were brought in entire. At all the five stations separate plates of the molar teeth of the Mammoth, evidently intentionally introduced, were found. At Les Eyzies and La Madelaine worked ivory was met with. At the former, a metacarpal of a Lion (?) bore the marks of scrapings, such as are often found on the bones of herbivores eaten by savage man.

At Laugerie-Haute, where worked flints like lance-heads[1] were comparatively abundant, arrow-heads and harpoon-heads of bone were almost entirely absent; whilst the latter implements are found in great numbers at Laugerie-Basse, at La Madelaine, and even at Les Eyzies, where scarcely any of the well-finished lance-heads have been met with. The figures of animals engraved or sculptured on stone, on bone, or on Reindeer horn with a skill and accuracy exhibited by few existing wild tribes, have been met with

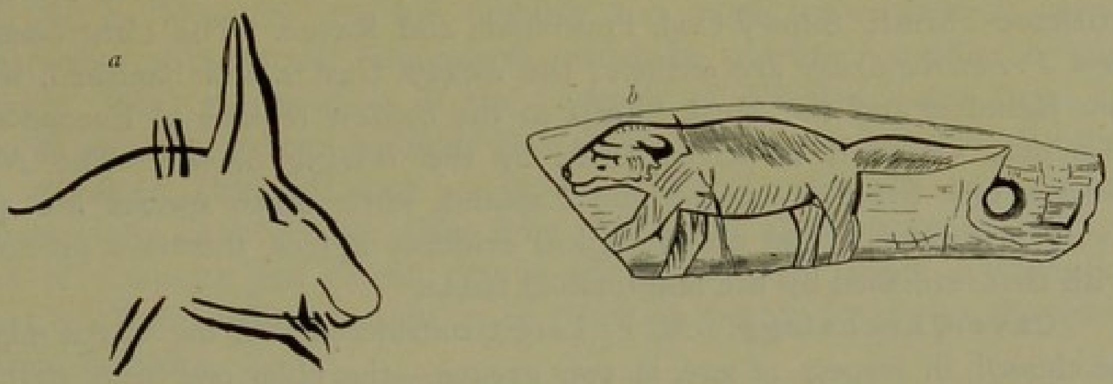


FIG. 245. *a. Head of Ibex* (?): *part of a nearly entire animal engraved on the brow-antler of a Reindeer;* Laugerie-Basse. *b. Outline figure of a Glutton, cut on a piece of Reindeer's antler, and perforated for suspension*; from one of the Dordogne Caves.
(Both these figures are reproduced from the sketches in 'Reliquiæ Aquitanicæ.')

only at three stations as yet, namely, Les Eyzies, Laugerie-Basse, and La Madelaine. The cave of Le Moustier, which is at a higher level, has yielded rudely worked flints of a special type, differing from those of the other locations, and approaching in form the implements of the valley-gravels of St. Acheul and Abbeville. On the other hand, there has not been found there a single worked bone, nor any engraved or sculptured figures. Nevertheless the fauna of the several Stations appear to be almost the same; only at Le Moustier the Reindeer is less dominant numerically than at the other caves[2].

The remains of *Elephas antiquus*, Hippopotamus, and Machairodus, have not been met with in the Dordogne Caves; but the Cave-Bear, Wolf, Fox, and the other cave-animals of Britain, are found; whilst in addition there are—

Antilope rupicapra ...	*Chamois.*	Capra Ibex	*Ibex.*
„ Saïga	*Saiga.*	Ovibos moschatus ...	*Musk-Ox.*

[1] Long, narrow, carefully chipped lanceolate flints resembling a Scandinavian (neolithic) type.

[2] *Op. cit.*, p. 5. See also Sir John Lubbock's account of these caves and the valley-drifts in his interesting 'Prehistoric Times,' chaps. viii. and ix.

These caves of the Dordogne present us, further, with a class of remains which have not been found in British caves, namely, bones of Birds brought into the caves by the agency of early Man. M. Alphonse Milne-Edwards [1] gives an interesting description of those found in the French caves. In Dordogne [2] they comprise [3]—

Aquila fulva	*Golden Eagle.*	Turdus viscivorus	*Misletoe thrush.*
Falco communis ...	*Peregrine Falcon.*	Tetrao albus, ...	*Willow-Grouse.*
„ tinnunculus ...	*Kestrel.*	„ urogallus	*Capercailzie.*
Vultur monachus ...	*Black or cinereous Vulture.*	„ mutus	*Ptarmigan.*
Gypaëtus barbatus ...	*Bearded Vulture.*	Œdicnemus crepitans ...	*Thick-knee.*
Nyctea nivea	*Snowy Owl.*	Grus primigenia	*Primitive crane.*
Corvus corax	*Raven.*	Anas boschas	*Wild duck.*
„ corone	*Carrion Crow.*	Cygnus ferus (?)	*Wild Swan.*
Pyrrhocorax primigenius	*Cave Chough.*	Nucifraga Caryocatactes	*Nutcracker.*
„ Alpinus	*Alpine Chough.*	Pica caudata	*Magpie.*

Of these, the most common are the Willow-Grouse, Alpine Chough, Misletoe-Thrush, Snowy Owl, Ptarmigan, and Raven. The *Cave Chough* and *Primitive Crane* are extinct; the *Snowy Owl* is now banished, with the Reindeer and the Musk-Sheep, to the coldest regions of Europe and America, where it is accompanied by the *Willow Grouse.* The *Nut-cracker* now lives in Sweden and Lapland, while other species are still living in France. The ornithological evidence agrees, therefore, precisely with that furnished by the Mammalian fauna.

Cave-Chronology. M. E. Lartet considered that the Caves might be classed, in respect of age, in two groups,—the older one being characterised by the numerical predominance of the Mammoth, and the latter group by that of the Reindeer. M. de Mortillet has proposed a more elaborate chronological classification of the Quaternary Cave- and Drift-deposits, of which the following, taken in the order of relative age, is an outline [4].

TYPICAL CASES.	CHARACTERISTIC REMAINS. (These have reference to France and Belgium only.)
1. MAGDALENIAN EPOCH.	
Cave of La Madeleine. Cave of Bruniquel. Kent's Cave } The Upper Creswell Caves } Beds only.	*Sculptured and Engraved bones.* *Felis pardus, Hyæna striata, Cervicapra Saïga, Cervus tarandus, Bos primigenius, Ursus Arctos, Canis lupus, Gulo borealis, Elephas primigenius.* (No Rhinoceros.)
2. SOLUTREAN EPOCH.	
Station of Solutré. Caves of Les Eyzies and Laugerie-Haute. Creswell Cave (the Lower Beds). Cave of Baussé-Raussé.	*Equus fossilis, Cervus tarandus, Bos primigenius, Bos Bison, Cervus dama, Ursus ferox, Felis spelæa, Hyæna spelæa, Elephas primigenius, Rh. tichorhinus.*

[1] 'Reliquiæ Aquitanicæ,' p. 226.

[2] I have omitted those of Le Moustier and the Gorge d'Enfer, as there seems some doubt as to their mode of introduction.

[3] Some of the English names are altered in accordance with Prof. Newton's criticisms, etc.

[4] 'Le Préhistorique Antiquité de l'Homme,' and various Memoirs.

TYPICAL CASES.	CHARACTERISTIC REMAINS.
3. MOUSTERIAN EPOCH.	
Cave of Le Moustier. Station of Cœuvres (Soissons). The Valley-gravel of Montières (Amiens). Kent Cave (in part). Wookey Hole. Drift-deposits of the Valley of the Lark.	*The Engis Skull.* *Ovibos moschatus, Equus Caballus, Cervus Canadensis, C. megaceros, Hyæna spelæa, Felis leo, Rhinoceros tichorhinus, Elephas primigenius.*
4. CHELLEAN EPOCH.	
Drift beds of Chelles. " of St. Acheul (Amiens). " of Menchecourt (Abbeville). " of Hoxne (Suffolk). Detrital Laterite (Madras).	*The Neanderthal Skull; Human Remains of Denise* (Auvergne). *Ursus spelæus, Machairodus latidens, Hippopotamus amphibius, Rhinoceros Merckii* (*Megarhinus*), *Elephas antiquus, E. primigenius.*

M. de Mortillet attaches possibly too much importance to certain characters of the stone implements, which he considers peculiar to each epoch. That the infilling of the Caves is of different dates there can be no doubt; and we consider this an important attempt towards their classification, although there are many points of geological position and stratigraphy on which we differ from the author of the scheme, which is full of elaborate and careful details relating to each epoch. We regret that our limits will not allow us to dwell at greater length on this interesting question.

Belgium. The caves in the valley of the Meuse were made famous at an early date by Schmerling[1] and Spring; while those in the valleys of the Lesse and Molignée have been more recently explored by Dupont[2]. In the caves of Engis, Engihoul, Chokier, and others near Liége, Schmerling found the bones of the Cave-Bear, Mammoth, Rhinoceros, Hyæna, etc., and, mixed up in the same breccia, were human bones and skulls, together with flakes and worked flints. As the result of these investigations, Schmerling concluded that the remains of man were contemporary with those of the extinct Mammalia. As, however, the caves contained also fragments of coarse pottery, and bore other evidence of having been at one time inhabited by Neolithic Man, by whom the cave-floor might have been disturbed or its contents mixed, his conclusions were not accepted. The cave of Engis had also a communication through a fissure with the surface, and, like some of the other caves, had been filled with breccia from above.

M. Dupont opened out a new and rich district, in which he found some sixty bone-caves. Several of these were true caves: others were rock-shelters, as in Dordogne, though formed under different conditions, as many

[1] 'Recherches sur les ossements fossiles découverts dans les cavernes de la province Liége,' 1833.
[2] 'L'Homme pendant l'Age de la Pierre,' 1872.

of these Belgian caves had been subject to inundation by the river. In the valley of Montaigle, three caves, situated about 100 feet above the level of the river, were found to contain the remains of Mammoth, Bear, Hyæna, Reindeer, etc., brought in by Palæolithic Man, whose signs of habitation were shown in the hearths and flint implements interspersed with the cave débris.

In caves at lower levels near Dinant, M. Dupont found the above and other cave-animals, together with rude figures carved out of Reindeer horns, and antlers etched with some simple form of ornamentation. In the same cave (Trou Magrite) there were fragments of coarse pottery. In the Trou de la Naulette a human lower jaw was found. In the cave of Goyet there were five ossiferous layers, and a still greater number of objects in bone; amongst them a harpoon made of Reindeer antler; and also some human bones.

The Trou du Frontal in the valley of the Lesse was a rock-shelter that had served as a burial-place. Here were found parts of 24 human skeletons, coarse pottery, and rude ornaments. There were found in this and two other caves a number of fossil shells—such as *Turritella*, *Natica*, and even *Cerithiun giganteum*, with holes drilled through them, which must have been brought from the Tertiary strata of Champagne. The Reindeer is found in these caves, but the Mammoth and Rhinoceros are absent; the Dog and several species of Bird are present. M. Dupont places these caves in the 'Reindeer Age': the others in the 'Mammoth Period.' It may be a question, however, whether some of these caves are not of Neolithic age.

Germany. Caves are common in the hilly parts of Germany and Hungary, and contain the same group of animals as those in England, only the proportion in the number of the Glutton and some other of the existing indigenous Mammalia is larger. Amongst the most remarkable of the caves are those on the banks of the River Weissen in the district of Muggendorf in Bavaria; they have long been known, and often described by German geologists. The Weissen and its tributaries there traverse a high limestone plateau, through which the river-valleys are excavated to the depth of 200 to 300 feet. Within a space of six miles by seven there are more than 20 caves, of the principal of which an account is given by Dr. Buckland in his 'Reliquiæ Diluvianæ.'

The Cave of Gailenreuth was of great extent, and the cave-earth thickly covered with stalagmite. Bones and skulls of the Cave-Bear—the remains of animals of all ages which lived and died through successive generations in the cave—largely preponderated over the other usual cave-animals, some of which may have only occasionally visited the cave, whilst others were brought in as prey. Amongst the remains were those of Lion, Hyæna, Fox, Wolf, Glutton, Horse, Bison, Reindeer, and Red Deer. The Mammoth and Woolly Rhinoceros were absent, but the remains of these animals were found in other caves in the district.

Russia. There are caves in the Ural mountains; and from one in the province of Tomsk in Siberia, Rhinoceros, Bear, Hyæna, Cat, Glutton, Wolf, Horse, Deer, Ox, and Lagomys are recorded. It thus appears that a similar Mammalian fauna spread in these times over the whole of Europe north of the Alps, and extended into northern Asia.

The South of Europe. It has recently been discovered that the Reindeer strayed to the southern slopes of the Pyrenees, but its remains have not been found beyond. Nor have the remains of the Mammoth, Woolly Rhinoceros, or Musk-Ox been met with in Spain, whereas the *E. antiquus* and *R. hemitœchus* ranged to Gibraltar. The Mammoth is replaced by the African species; remains of the existing African elephant are also found in the Valley-gravels of the neighbourhood of Madrid.

The extraordinary series of fissures filled with ossiferous breccia, in the limestone rock of Gibraltar, have been described by Dr. Falconer[1] and Mr. Busk[2]. One of these fissures, known as the 'Genista Cave,' has been explored to the depth of 300 to 400 feet. An enormous quantity of animal remains, varying in age from the Prehistoric to the Pleistocene epoch, were obtained. Some were imbedded in a hard and others in a soft matrix; and in many instances bones belonging to the same individual were found, either in juxtaposition or at no very great distance apart. Not a single bone bore tooth-marks, although the Spotted Hyæna then lived on the rock, which was covered with an abundant arboreal vegetation, harbouring a numerous fauna of large herbivorous and carnivorous animals.

Besides those above mentioned, the Genista Cave yielded the remains of—

Ursus (ferox?), *Rich.*	Cervus elaphus, *L.*
Felis pardus, *L.*	„ dama, *L.*
„ pardina, *Oken.*	Capra ibex, *L.*
„ caligata, *Temm.*	Bos primigenius, *Boj.*
Canis vulpes, *L.*	Sus scrofa, *L.*
Equus caballus, *L.*	Lepus cuniculus, *L.*

These species are for the most part of Southern or African affinities, although several of them had also a wide northern range during the Pleistocene period. The Panther still lives on the opposite African coast, and the *Felis caligata* is a cat which seems to have had a very extensive range from one end of Africa to the other, and was regarded as sacred by the ancient Egyptians. The Fallow Deer is now a native of Northern Africa and Sardinia.

Sicily. The ossiferous caves on the face of the rocky hills around Palermo, and at an elevation of 30 to 50 feet above the plain, have attracted notice from remote antiquity. The best known is the large open 'Grotta

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[1] 'Palæontological Memoirs,' vol. ii. p. 554.
[2] 'Trans. Zool. Soc.,' vol. x. part ii.

di San Ciro,' explored by Dr. Falconer in 1859. The basement-bed in this cave is a thin bed of sand with marine shells of recent species. Above this is a large mass of hard bone-breccia 20 feet thick—then follow blocks of limestone and cave-earth with an enormous quantity of bones, chiefly of Hippopotami. At one time these bones were largely used for the manufacture of lampblack at Marseilles. In six months of 1829 as much as 20 tons weight were exported. This shows how extraordinary the numbers of these animals must have been. So large an accumulation could only

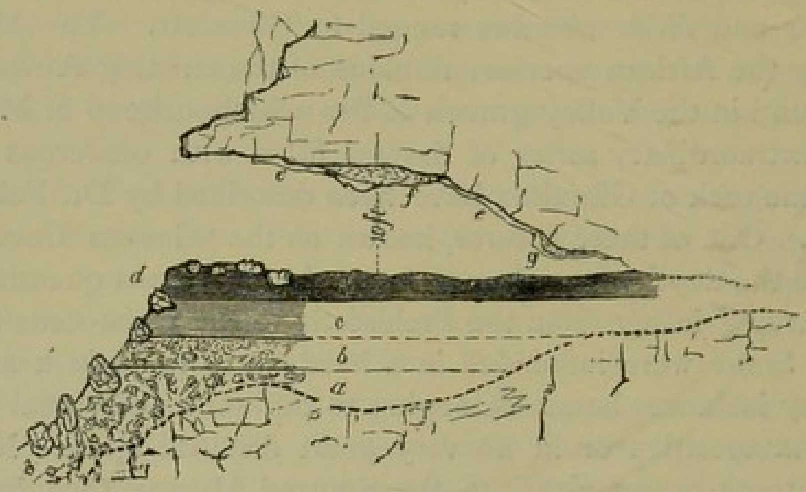

FIG. 246. Section of the Grotta di Maccagnone, Carini, near Palermo; in Hippurite Limestone. (Falconer.) *a. Bone-breccia with blocks of limestone. b. Loam and porous stalagmite. c. Yellow cave-earth with blocks of limestone. d. Superficial soil with blocks of limestone. e. Stalagmite. f, g. Roof breccias.*

have resulted from the cave having been frequented by long successive generations of these huge creatures. The lower part of the walls of the cave was polished (by some animals rubbing against it), and thickly drilled with Pholas-borings of a previous period, but now filled with the matrix of the bone-breccia.

In the Grotta di Maccagnone, near Carini, a nearly similar succession of deposits occurs; together also with bones of Hippopotamus, Ursus, Equus, Felis, and Elephas, and bones and coprolites of Hyæna. A point of special interest in this cave was the discovery, at 10 feet above the present floor, of a mass of breccia of the same character as that forming that floor, but with more calcareous cement, adhering to the sides and roof of the cave. Dr. Falconer discovered in this breccia bits of carbon, and numerous fragments and flakes of hornstone, similar in make to the flint flakes of Kent's Hole and other caves. This cave therefore, like that of Brixham, must have been at one time filled, or nearly filled, to the roof. In other Sicilian caves the bones of Carnivora preponderate.

The Hippopotami were of two species, *H. Pentlandi* and *H. major*; the Elephant—*E. Africanus* and *E. antiquus*; the other animals agreed closely with those of Gibraltar.

Malta. The Zebbug and other caves of Malta have been explored by Admiral Spratt[1], with most interesting results. Besides the remains of the same Hippopotami as in Sicily, there have been found in these caves the remains of several species of Elephant, associated with the remains of a large *Myoxus*, a Tortoise, and Birds. One of these Elephants was a peculiar pigmy species (*E. Melitensis*, Falc.), not more than five feet high. A tooth of this little Elephant is here represented of natural size.

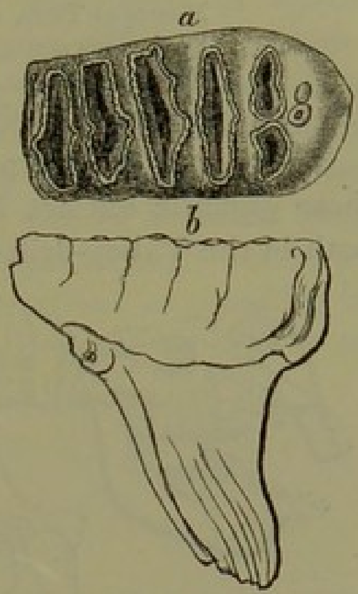

Fig. 247. Molar of the pigmy Elephant of Malta (*E. Melitensis*, Falc.). Nat. size.
a. Crown. b. Side view of tooth.

There was evidence also of two other small species of Elephant, one about three and the other seven feet high. In the Melliha Cave, Admiral Spratt found only the remains of Hippopotamus, whereas there were none in the Zebbug Cave, where the bones were much gnawed by some animal of the size of a jackal.

Dr. Falconer concluded from the character of the animals found in Sicily, Malta, and Gibraltar, that at some comparatively recent geological period there must have been a land communication between Africa and these districts. The soundings on the Adventure Bank, between Sicily and Tunis, and on the Medina Bank, between Sicily and Tripoli, come within the depth of 80 to 100 fathoms, with the exception of a narrow passage 200 to 300 fathoms deep. A subsidence of some 600 to 900 feet would have proved sufficient to submerge the old land-area formerly connecting the two continents; the deeper channels may have been produced by later marine denudation (see contour-lines on Map).

India. The almost complete absence of ossiferous caves in the Indian Peninsula is a very singular feature. They have been found only in one locality,—the limestones of the Karnúl series near Bánaganpili. The floor of the one explored was covered with stalagmite, below which was a red cave-earth with numerous mammalian bones. Unfortunately the specimens are lost and the locality forgotten.

Australia. The ossiferous caves of Australia contain remains of extinct gigantic Marsupials, which are represented at the present day by species of far less size. The *Diprotodon* was a huge vegetable-feeder, agreeing in some respects with the Wombats, and having a skull three feet in length. The *Macropus* was a creature the size of a Rhinoceros. The *Thylacoleo* is supposed by Owen to have been a powerful carnivorous and predatory Marsupial, but it has also some characters of a vegetable-feeder.

[1] 'Quart. Journ. Geol. Soc.,' vol. xxiii. p. 283; see also Falconer, *Op. cit.*, vol. ii. p. 292; and Leith Adams, 'Trans. Zool. Soc.' for 1874.

Associated with these peculiar types are forms allied to the smaller Kangaroo-rats.

The chief locality for the caves is Wellington Valley in New South Wales. Amongst the species described by Owen are—

Macropus Titan, *Ow.*	Diprotodon Australis, *Ow.* Fig. 248.
Thylacinus major, *Ow.*	Nototherium Mitchelli, *Ow.*
Phascologus altus, *Ow.*	Procoptodon Goliath, *Ow.*
Thylacoleo carnifex, *Ow.*	

Annexed is a restoration, by Owen, of one of the most remarkable of these gigantic extinct Marsupials, the remains of which have been found both in the Valley-drifts and in the Caves.

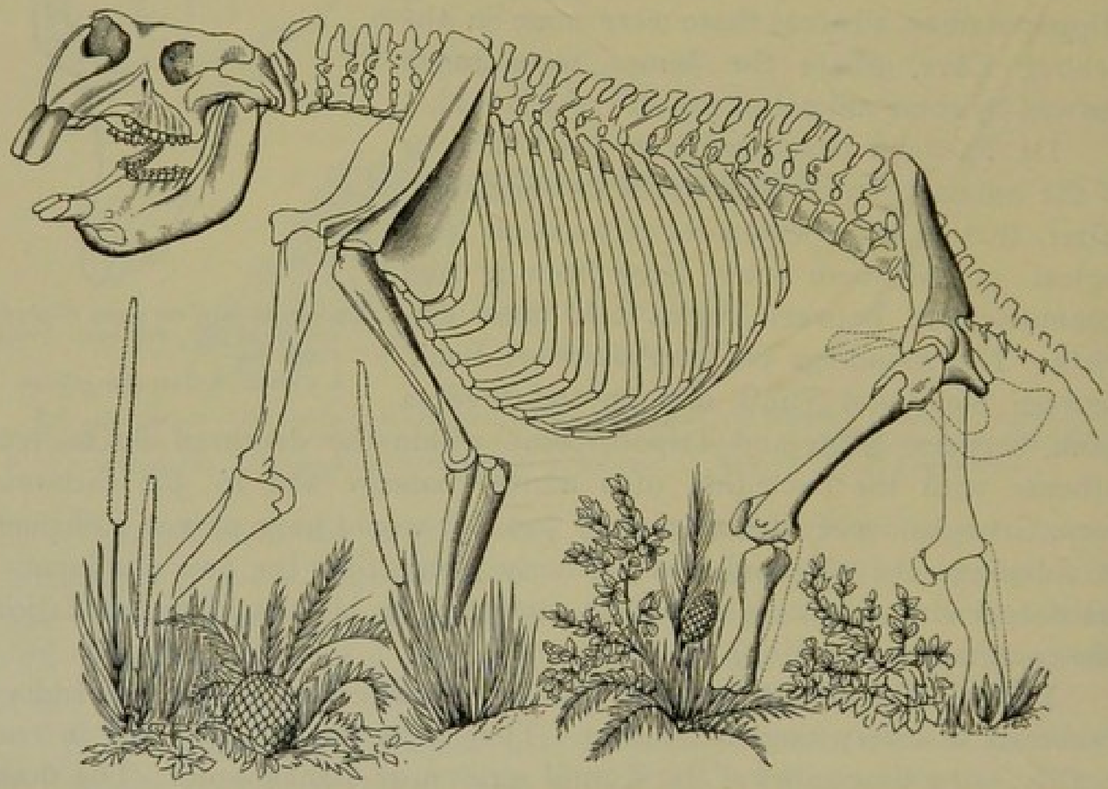

Fig. 248. *Restoration of Diprotodon Australis.* (After Owen; reduced.)

North America. There are numerous caves, some of very large size, in the limestones of the Ohio and Mississippi valleys, and in Pennsylvania and Virginia. Many of these are yet water-courses[1], and only a few of the caves seem to have been the resort of the wild animals of Quaternary times. Amongst these, and in some bone-breccias, Professor Cope has recognised a number of extinct Edentates, Ungulates, and Rodents, besides

[1] Professor Shaler states that the limestones of the Cincinnati group in Kentucky are riddled by water-channels, and that in many parts of the country swallow-holes or pits average 100 to the square mile. The aggregate length of the underground water-passages he estimates at some thousands of miles, while in the belt of Carboniferous Limestone there are at least 1000 miles of open water-channels, which have been formed by a process of undermining, and give access to the underground passages or caverns.

others, some of which are still living in the country. They include species of Megalonyx, Mylodon, Casteroides, Arctomys, Sciurus, Lepus, Tapirus, Equus, Felis, Dicotyles; together with the more northern class of animals, such as Ursus, Cervus, Bison, Elephas, and Mastodon.

South America. Lund has described the cave-fauna of Brazil, which comprises some fifty genera, and includes species of Dasypus, Megatherium, Megalonyx, Didelphis, Mastodon, Equus, Dicotyles, Felis, Canis, Hyæna, with numerous Rodents and some Monkeys. In one of the many (200) caverns examined, Lund found human bones in association with those of extinct animals; but, though fossilised and very old, he doubted from various circumstances whether the two were contemporaneous. He however may have been influenced by the same prepossessions as prevailed in the case of Kent's Hole; and it would be very desirable therefore to examine these caves again.

CHAPTER XXXII.

THE QUATERNARY PERIOD (*concluded*).

THE ALLUVIAL OR RECENT EPOCH.

RAISED BEACHES: HEIGHT ABOVE SEA: COMPOSITION: FOSSILS: ERRATIC BLOCKS. 'HEAD': LOCAL CHARACTER, BRIGHTON. SELSEA: FOREIGN BOULDERS: LOCAL SHELL-BED: RECENT SPECIES: THEIR SOUTHERN CHARACTER. PORTLAND BILL: BEACH-SHELLS. TORQUAY. DEVON AND CORNWALL. BIDEFORD BAY. BOULDER-PEBBLES. WESTON-SUPER-MARE. CHILTON-TRINITY SHELL-BANK. SOUTH WALES. GOWER CLIFFS. MEWSLADE AND RHOS SILI BAYS. SCOTTISH BEACHES: NEWER AND OLDER. FRANCE: SANGATTE: LAND SHELLS. GUERNSEY AND JERSEY. BRITTANY: BOULDER BEACHES: FOREIGN ROCKS: THEIR ORIGIN. MEDITERRANEAN AREA. BEACHES OF MANY AGES. GIBRALTAR. TANGIERS. SICILY. ASIA. AUSTRALASIA. SOUTH AMERICA. NORTH AMERICA. CLOSE OF THE QUATERNARY PERIOD. CHANGE OF CONDITIONS. NO MEASURE FOR COMPARISON. NEOLITHIC MAN. HIS DATE. ALLUVIAL BEDS. THE THAMES VALLEY; TILBURY DOCKS; HUMAN SKELETON. SEVERN VALLEY; SECTION NEAR LYDNEY BASIN. CORNWALL; STREAM-TIN WORKS; SECTION IN PENTUAN VALLEY; HUMAN REMAINS. NEOLITHIC FAUNA. SUBSEQUENT SUBSIDENCE. CONTINUITY OF GREAT DELTAS.

Raised Beaches. In this case again we have to deal with beds contemporaneous with a portion of the Valley-drifts. Fringing the south coast of England, the north coast of Cornwall and Devon, and the coast of South Wales, are to be found lodged here and there, generally in the more sheltered parts of the cliffs, remnants of an old 'Raised Beach,' which was once continuous all round the south and south-west coast. These remnants vary from 10 to 30 feet in height above the present beach. The variation in level may sometimes be owing to the fact that the old beach has been intersected at varying distances from its summit-level, but this will not account for the extreme differences, such, for example, as with the inland beach near Chichester, which attains a height of 80 to 90 feet above the sea-level. It cannot therefore be owing to a change of the sea-level; but must be due to a slightly unequal elevation of the land since the time the beach was formed, although that elevation was, on the whole, singularly uniform over an extensive area.

The encroachment of the sea on the soft Cretaceous and Jurassic strata on the coast between Kent and Devonshire has removed the greater portion of the old Beach. Short portions of it, however, remain on either side of Brighton—on the shore west of Bognor—inland near Chichester—in the cliff near Bembridge—and on the extreme south point of the Isle of Portland. The encroachment of the sea has removed all traces of the Beach on the coast of West Dorset, but on the coasts of Devon and Cornwall, where the palæozoic rocks have resisted denudation, it is much more continuous, as shown in the following plan.

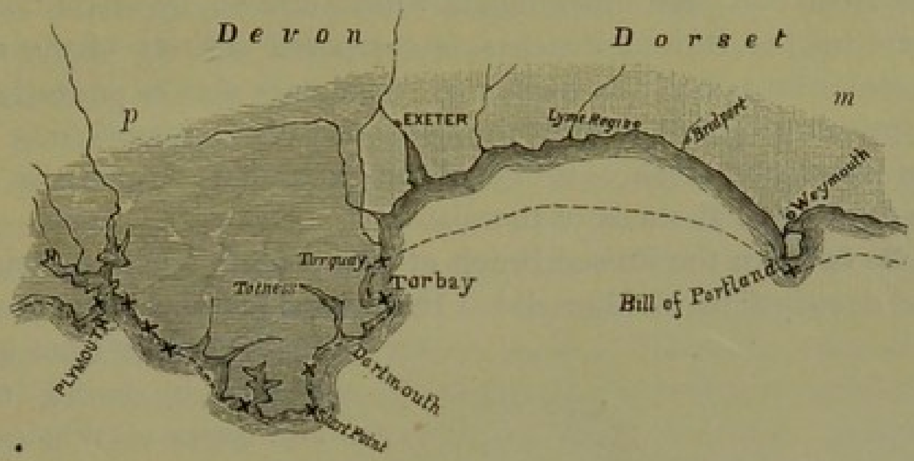

Fig. 249. Line of the old Raised Beach on the coasts of Dorset and Devon. 1 inch = 27 miles. ---- *Original line.* × *Patches of the Beach left on the present cliffs.* *m. Mesozoic strata.* *p. Palæozoic strata.*

The Beach is somewhat variable in its character. At places it consists simply of a bed of well-rolled shingle without the trace of a shell; at others it contains a few shells; while occasionally the shingle is largely intermixed with sand and shells. These shells are all of recent species[1], and often retain their colour and organic matter, so that they look almost as fresh as those on the present Beach. Nevertheless, they are of Quaternary age, for the mass of débris or Head, which commonly overlies them, contains remains of the Mammoth and other of the extinct mammalia. Not more than 25 to 30 species of Mollusca have as yet been recorded from the Raised Beaches; the most abundant are—

Ostrea edulis, *L.*	Littorina littorea, *L.*
Cyamium minutum, *Fabr.*	,, rudis, *Mat.*
Cardium edule, *L.*	Purpura lapillus, *L.*
Mytilus edulis, *L.*	Nassa incrassata, *Müll.*
Tellina Balthica, *L.*	Buccinum undatum, *L.*
Saxicava rugosa, var. arctica, *L.*	Patella vulgata, *L.*

with several species of Trochus and Rissoa. Foraminifera and Entomostraca of recent species also occur. The shells are such as are now common in the littoral zone on the western coasts of Europe; but most of them have a

[1] Dr. Gwyn Jeffreys noted one exception to this in an undescribed species of Rissoa found in the raised beach of Portland.

high northern range, and there is an absence of the more southern species.

The Beach occasionally consists of well-rounded boulder-pebbles, six to 12 inches or more in diameter. In places it also contains blocks more or less angular, and often of large size, of rocks foreign to the locality, and which could hardly have been transported to their present position by any other means than floating ice. It is clear, therefore, that these several conditions point to the continued prevalence up to this time of a very considerable degree of cold.

The Head, on the other hand, which almost invariably lies upon and covers up the Raised Beaches, is composed entirely of the débris of the adjacent strata; and the harder fragments are always perfectly angular and sharp. Again, this débris, though generally unfossiliferous, contains in places bones and teeth of some of the Quaternary Mammalia, together with the existing land shells of the district.

At Brighton the Raised Beach of Kemp Town has been long known, from the descriptions of Mantell[1]. It contains few shells, but many of its chalk pebbles have been perforated by boring mollusca, and bones of Whales are occasionally met with. There are also a few boulders of foreign rocks, but none of large size. The Head, which here overlies the Beach, is composed entirely of local chalk and flint rubble, roughly stratified, and 50 to 60 feet thick. Some portions of it are concreted and form a hard stone known as the 'Combe-rock.' In this rubble, which Mantell designated the 'Elephant-bed,' remains of the Mammoth, Ox, Deer, etc., are not rare.

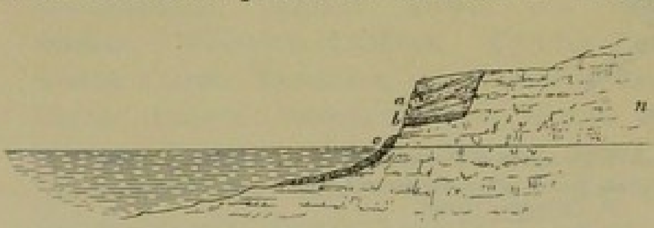

Fig. 249*. Diagram-section across the coast east of Brighton. *a. Elephant-bed (head or rubble). b. Raised beach. c. Present beach. n. Chalk.*

This Beach extends thence across the low ground by Hove to Worthing and Selsea, where it presents special features. It is there a sea-bed rather than a sea-beach (the old coast-line lying further inland), and consists of a yellow clay with some subordinate seams of shingle and a few shells, and is remarkable for the large number of great, more or less angular, blocks of various old and crystalline rocks it contains. Mr. Godwin-Austen found amongst them blocks of red and grey porphyritic granites, syenite, greenstone, mica-schist, quartz, quartzite, and sandstone[2]. One fine block of granite measured 27½ feet round. I found similar blocks strewed widely over the surface of Hayling Island. The parent rocks from which these blocks have been derived have not yet been well identified. Godwin-

[1] 'Fossils of the South Downs,' 1822, p. 277; and 'Geology of the South-East of England,' 1833, p. 27.
[2] 'Quart. Journ. Geol. Soc.,' vol. xiii. p. 40.

Austen thought that some might be referable to the rocks between Torbay and the Land's End, or that they might be compared with a series of rocks from the Cotentin and the Channel Islands. He further suggested that they might possibly have come from an old palæozoic ridge of rocks in the Channel, now submerged.

Selsea Shell-bed. Associated with these coast-deposits at Selsea is a local bed of fine silt with a very anomalous group of shells. It is said to underlie the clay and shingle with boulders; but its superposition has not been well proved. I have never found it under the boulder-bed, although at places it clearly lies upon the 'Bracklesham beds.' This shell-bed has been described by Mr. Dixon; and more recently the shells have been re-examined by Mr. A. Bell, who has increased the list of this small local deposit to the number of 140 species [1]. All the species are recent, although a large proportion are not now living on the Sussex coast; thirty are still to be found on the coasts of Devonshire and Cornwall, the Channel Islands, and North of Spain; whilst six or eight are to be met with only on the coast south or east of Gibraltar—*Lutraria rugosa* ranging from Portugal to Tunis and the Canary Islands; *Chiton siculus*, *Fissurella costaria* from the South of France, along the shores of the Mediterranean; and *Pecten polymorphus* on the coasts of Portugal and South Europe. Another peculiarity of this fauna is the very large size attained by some of the shells. Specimens of the *Pholas crispata* have been found six inches in breadth. Amongst other characteristic shells of this deposit are—

Pecten maximus, *L.*	Littorina littorea, *L.*
Tapes decussatus, *L.*	Nassa reticulata, *Flem.*
Mactra stultorum, *L.*	Trochus cinerarius, *L.*
Solen vagina, *L.*	Phasianella pullus, *L.*
Cyamium minutum, *Fabr.*	Rissoa cimex, *L.*
Saxicava rugosa, *Lam.*	Pleurotoma rufa, *Mont.*

Echinocyamus pusillus and *Spatangus purpureus* also occur, together with species of recent Foraminifera.

This fauna is so distinctly southern in its general relations, and so recent in all its aspects, that it is difficult to assign it to any part of the Glacial Period. At the same time the presence of *Elephas antiquus* and *E. primigenius*, the remains of which at Selsea are referred to this zone, takes it back to Quaternary times. But we know that the Mammoth survived to the close of that time, for its remains are found in the Head which overlies the Raised Beach; so this may be a local deposit more recent than the Boulder-Bed or Raised Beach, and yet older than the Head, and formed at a time when warmer southern currents had set in on the south coast at the close of the Glacial Period; but this is uncertain.

[1] 'Annals and Mag. Nat. Hist.' for July, 1871; 'Geology of Sussex,' edited by Professor Rupert Jones, 1878, chap. ii.

Portland Bill. Between the Isle of Wight and that of Portland the old Beach has been swept away, but at the extreme southern point of the latter island a very instructive remnant is preserved on the top of the cliff[1], at a height of 24 feet, gradually increasing northward to 53 feet, above the present Beach. At the 'Bill' the Beach (*c*) consists of a mass of well-rounded shingle, but further north, on the east cliff, it passes into a sand full of shells in an excellent state of preservation, and with their original colours often retained. Species of the common Littorina, Patella, Purpurea, Ostrea, and Mytilus are very abundant. The tiny *Cyamium minutum*, a Greenland shell, which is gregarious in some places among sea-weeds, and under stones at low water, occurs in thousands. With the exception of *Trochus helicinus*, Fabr., found on the Irish and Yorkshire coasts, and one undescribed species of *Rissoa*, all the other twenty-two species are now living on the Dorset coast, although the proportions in which they occur are different.

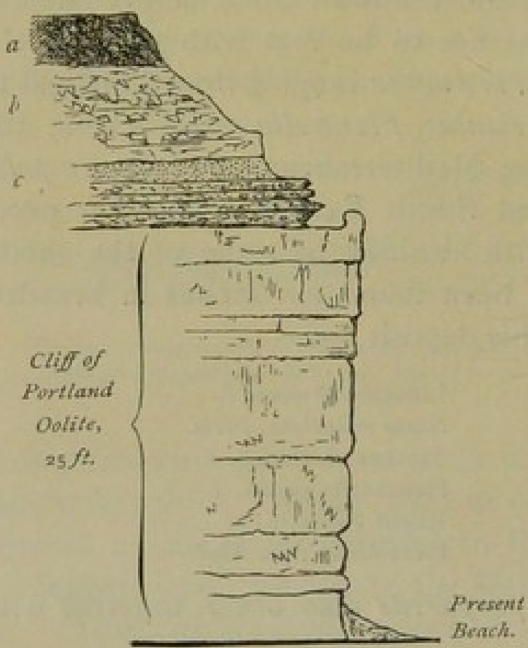

Fig. 250. Raised Beach, Portland Bill.
a. Angular rock débris, 5 ft. b. Loam with land shells and angular débris, 6 ft. c. Sand, Shells, and well-rolled pebbles, 5 ft.

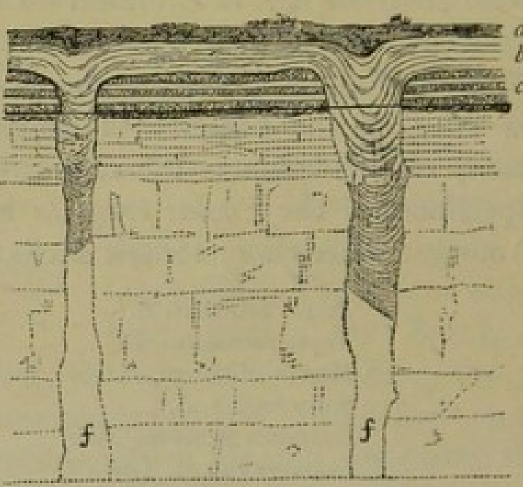

Fig. 251. *Fissures (f) in the Portland Rock, which the Raised Beach (c) and 'Head' (a, b), having been let down, have partly filled.*

This Beach is of further interest from the circumstance that it exhibits the disturbances which the Island has since undergone. Near the Bill the rock is traversed by numerous longitudinal fissures, the result probably of Earthquake movements, and into these fissures the Raised Beach has been let down to a greater or less depth, as shown in the accompanying figure.

Devon and Cornwall. No Raised Beach is then met with until we reach the hard Palæozoic rocks of Devonshire. There are portions of one at Teignmouth and near Torquay. That at Hope's Nose has been long known from the description by Mr. Godwin-Austen in the

[1] Whitaker, 'Geol. Mag.,' vol. vi. p. 438; the Author, 'Quart. Journ. Geol. Soc.' for 1875.

'Trans. Geol. Soc.' Between Torquay and Plymouth Raised Beaches occur frequently. (See Fig. 249.)

They are still more common on the coast of Cornwall. Mr. W. A. E. Ussher[1] gives a list of twenty localities where they are to be seen. They are in all cases covered by a Head; the Beach is often a true Boulder-beach, and shells are generally scarce.

In Bideford Bay there are some fine examples of Raised Beaches.

Near the village of Croyde[2] the Beach, which is from 15 to 25 feet above the sea-level and in places 12 feet thick, consists of a sandy shingle like the present Beach, and contains the ordinary Beach shells, which, though few in species, are numerous as individuals. When I first visited this Beach, a large block of granite, which, according to Mr. Pengelly, has not been derived from either Devon or Cornwall, and probably weighed

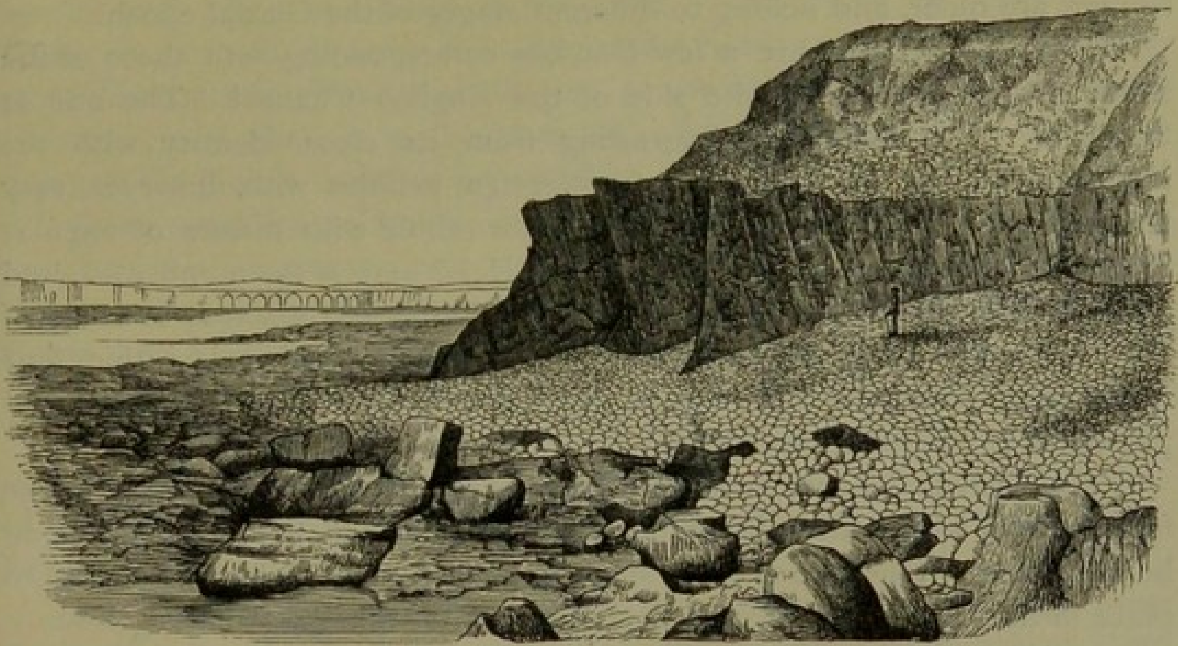

FIG. 252. *Raised Beach at Westward Ho.* (Reduced from a photograph by Mr. H. Spearing Green.)

10 to 12 tons, was implanted in the Beach. It may have come from Lundy Island. The rocks on the level of the Old Beach and under it are coated in places with *Balanus balanoides*. The Head attains in places a thickness of above 100 feet, and consists of sharply angular fragments of the adjacent slaty rocks, and of sands with a few land shells (Helix, etc.). At Westward Ho the Beach is composed of huge boulder-pebbles (some a foot or more in diameter), and covered by a small quantity of Head (Fig. 252).

Somerset. At Weston-super-Mare a patch of Beach was formerly visible at a height of 20 to 30 feet on the West Cliff. The sea has also left traces of its occupation of the low lands extending thence to the Mendip

[1] The Post-Tertiary Geology of Cornwall, 'Geol. Mag.' for 1879.

[2] It was described by Sedgwick and Murchison in 1836, 'Trans. Geol. Soc.,' vol. v. p. 279; Pengelly, 'Trans. Dev. Assoc.' for 1867.

and Quantock Hills in the bed of marine shells at Chilton-Trinity near Bridgewater.

Gower Cliffs. The coast of South Wales is fringed in many places by Raised Beaches. They are frequent in Gower, and two remarkably fine sections are exposed in the cliffs of Mewslade Bay, and along the whole length of Rhos Sili Bay. In the former, the common shells are *Littorina littorea*, *L. rudis*, *Patella vulgata*, and *Purpura lapillus*; and in the latter, *Turritella communis*, with a few *Nassæ incrassatæ*.

Scotch Beaches. It is doubtful whether the Raised Beaches which occur on the coasts of Scotland and part of Ireland are, although on a similar level, of the same age as those of the South of England. Some are probably newer; whereas those on the higher levels, such as the bold shingle-banks occurring at heights of from 50 to 150 feet in the Island of Jura, and others similar, are older, and belong to different stages of the Glacial epoch.

France. There are a few Beaches corresponding with those of the south coast on the opposite side of the English Channel. The one at Sangatte [1], near Calais, is interesting from its close identity with the Brighton Beach. It contains a few foreign pebbles with, however, very few shells, and has a similar Head of chalk-rubble with masses of angular fragments of flints. A peculiarity of the Head here is the number of land shells (*Pupa marginata*, *Helix concinna*, and *Succinea oblonga*) in some of the seams of chalk-rubble. A few rude and rolled palæolithic flint implements have also been found in the flint gravel into which this Head passes, as it falls to a lower level.

Guernsey and Jersey have been each surrounded by an old Beach, large fragments of which are still to be met with attached to the cliffs around both islands. They are of interest as proving how little change has taken place in the form of the islands since the close of the Quaternary period.

Brittany. M. Charles Barrois [2] has shown that in Brittany there are similar patches dotted at short intervals along the coast, at heights of from 10 to 40 feet above the present sea-level. In many places on the west coast of Finisterre the Raised Beach contains pebbles and blocks of granite, foreign to the district, of some considerable size, consisting of porphyry, cretaceous rocks, etc., with others of local origin; while in other places there are banks of boulder-pebbles, like those of Westward Ho and parts of Cornwall. M. Barrois ascribes the introduction of these foreign rocks to shore-ice formed on the adjacent coast and to river ice-rafts descending the Loire and its tributaries during the Glacial Period, and floating down the crystalline rocks of the central plateau together with débris of the Mesozoic and Tertiary strata through which the river flows. The tendency of these rafts

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[1] The Author, in 'Quart. Journ. Geol. Soc.,' vol. vii. p. 274, and 'Bull. Soc. Géol. France,' 3e Sér. vol. viii. p. 547.

[2] 'Ann. Soc. Géol. du Nord,' vol. iv. p. 179; and vol. xii. p. 239.

when they reached the sea was to drift northwards and eastward, so that they were stranded on the coast of Finisterre. There appears to be little or no Head over these Beaches, and they contain but very few shells.

Mediterranean Area. Raised Beaches are of frequent occurrence along the shores of the Mediterranean. They occur at Gibraltar, Tangiers, in Sardinia, Sicily, Crete, Cyprus, and on the coast of Asia-Minor. Unlike the Raised Beaches of the English Channel, these Mediterranean Beaches are of many ages. The movements were prolonged, and in some instances have not ceased at the present day (see Vol. I. p. 232). There are, however, two or three points which may possibly be correlated with the movement which affected the English Channel. At the south point of Gibraltar, Mr. Smith, of Jordanhill, found a tooth of *Elephas antiquus* in a Raised Beach, now removed; and Ramsay found a tooth of the same species at Tangiers in a Beach raised about 15 feet above the sea-level. In Sicily, the account given by Falconer of the San-Ciro Cave, with its basement-bed containing marine shells, and of the Maccagnone Cave on about the same level (*ante*, p. 507), agrees with the conditions under which the caves on the Gower coast were formed.

Over considerable tracts in **Persia** and **Arabia** marine shells of recent species are spread; and on the coast of the **Indian Peninsula** there are Raised Beaches with recent shells; but these are probably of more recent date than the English Beaches, although, in the absence of a land fauna and of known superposition, it is not possible to define their exact age.

It is the same with the coasts of **Australia** and **New Zealand** and parts of **Africa**. There is everywhere evidence of recent elevation of a moderate extent; but the precise date of the movements has yet to be ascertained.

In South America the observations of Darwin on the east coast show that in Buenos-Ayres there was an elevation probably of Post-glacial date; but along the west coast in Chili and Peru, it is evident from his other observations that there had been earlier movements repeated at intervals through a long anterior period.

In North America the conditions have been very similar. The movements were, as already mentioned, prolonged, of wide range, and more effective as they extended northward. In the Arctic regions the rise which began in the Glacial Period, and has continued to the present time, amounts, probably, in places to 1000 feet. Similar phenomena are exhibited in the Arctic regions of Europe and Asia (see Vol. I. Chap. xiii).

Close of the Quaternary Period. With the Raised Beaches and their overlying Head the Quaternary period comes to an end. The plain-gravels, into which the Head merges, pass under the adjacent flat lands and under the alluvial beds of the valleys; and with them concludes the long period of turbulent waters and devastating floods of the preceding cold and eventful period. The large Mammalia of that period succumbed to the change of climate; the Mammoth, Woolly Rhinoceros, and Hippopotamus die out and leave no descendants, for the living species are branches from the stocks at an earlier date; the Reindeer, Musk-Ox, Glutton, Lemming, and Lagomys migrate northward; the Leopard and Hyæna survive in more southern lands; while another section of the Mammalia remain and constitute part of the fauna of Europe at the present day. With the Molluscan fauna there was no such change; with greater adaptability and a greater range, the land and fluviatile shells survived, and present, with few modifications, the same facies now as then.

Change of Conditions. What the interval was between the end of the Valley-gravels and the beginning of the Alluvial and Peat-deposits we cannot say. There are no passage-beds: the change was thorough and complete [1]. Fine sediments, and marsh plants requiring quiet and limpid waters, succeed to the coarse drifts, shingle, and flood-sediments (Loess) of the Quaternary period. The special erosive agents, vigorous in the latter period, ceased their action, leaving the valleys either bare or covered by beds of gravel with an irregular and hummocky surface. All that the rivers have since done has been, perhaps, to recast some of the old drifts, and to level the inequalities of those old valley-surfaces by the slow and gradual deposition of silt and mud, and by the growth of peat—and so repair by gentle treatment the scars and asperities left by Quaternary floods and drifts. The latter has been their chief function. Consequently, instead of deep, broad troughs with uneven surfaces, our valleys now present water-levelled flats and extensive breadths of alluvium deposited by the rivers under their present régime; and the broad straighter lines of the old valley-channels are replaced by the contracted and tortuous channels along which the rivers now struggle. Instead of possessing their former force of excavation and transportation, the wasted rivers, with their silt-laden waters, fail even to retain power to remove all the surface débris carried into them by the rainfall, and, as a consequence of this loss of power, their channels are often clogged and their beds gradually raised.

No Measure for Comparison. And yet this is the period which some geologists would take as the measure of the forces in operation during geological times. As a minimum measure, and as a direction for the measure, they are right. It is a base which may serve as a safe guide; but it no more affords a true and sufficient guide than it would be to take the tottering paces and weakened force of an old man as the measure of what that individual was, and what he could do, in his robust and active youth. It may be right to take the effects at present produced by a given

[1] For information respecting the régime of rivers, the formation of their valleys, and the relation of the peat-beds to the gravels, the reader should consult the great work of M. Belgrand, 'La Seine; études hydrologiques.'

power as the known quantity, *a*, but it is equally indispensable, in all calculations relating to the degree of those forces in past times, to take notice of the unknown quantity, *x*, although this, in the absence of actual experience which cannot be had, can only be estimated by the results, and by a knowledge of the contemporaneous physical conditions. It may be a complicated equation, but it is not to be avoided.

Neolithic Man. As the existing fauna and flora became established, Neolithic Man appeared in these latitudes, bringing with him more finished tools—though still made of stone—domestic animals, and a progressive civilisation. His work and his remains are found low down in the alluvial deposits of the valleys, and these deposits are the one fairly available measure of the time which has elapsed since the close of the Quaternary period. This time is to be gauged by the amount of sedimentation in the valleys, and by the extent to which the sea has encroached on the land after the last elevation—that of the Raised Beaches and accompanying Head just described. That that time has been of any great length, geologically speaking, is not probable. For aught I see, Neolithic Man in these latitudes may have been a contemporary of the 'Shepherd Kings' of Egypt; and the break in the record we have here between Palæolithic and Neolithic Man may be filled up in the warmer regions of the world by a human occupation—wanting in these latitudes.

ALLUVIAL BEDS.

Space will not allow me to dwell on these recent deposits more than is necessary to give the reader some idea of the proportion and relation which they bear to the geological series previously considered. They have been described by Lyell[1], J. Geikie[2], Lubbock[3], Rupert Jones[4], and other writers, to whose works I would refer the reader.

The Thames Valley. I will merely take the few sections necessary to show these relations, which, owing to the want of natural sections, are not always easy to determine. In the Valley of the Thames, however, there have been not unfrequent opportunities of seeing sections of the alluvial deposits—(1) in the excavations made for the several great London docks, (2) the Dagenham breach, (3) the dock at Grays, and (4) especially in the last great work of this description—the Tilbury Docks. At the last-named place not only are the Alluvial beds of great thickness, but the valley is flanked by Pleistocene gravels, so that the relative position of the two deposits is clearly exhibited. The main valley-channel,

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1 'The Principles of Geology.'

2 'Pre-historic Europe;' 'Buried Forests and Peat-beds of Scotland.'

3 'Pre-historic Times.'

4 'Geol. Hist. of Newbury;' and 'Proc. Geol. Assoc.' 1880. 'Essays on the Natural History and Origin of Peat Moss,' by the Rev. R. Rennie, 1807–1810, may also be consulted with advantage.

which is cut through Chalk, is here two miles broad; and the intervening marsh land is perfectly flat. The docks extend over a considerable area on the north bank of the river, but whether they extend over the deepest of the old Quaternary river-channels is not known. We only know that in some places the Alluvial beds are 40 feet thick, and in others 70 feet. At the time that I visited the works the deeper sections were not exposed.

There were two beds of peat and patches of a third. The two constant beds occurred at depths of about 20 and 30 feet. The upper of the two maintained a uniform thickness of four to five feet, with all the regularity and, at a distance, aspect of a coal-seam. The following are the details of the section.

	feet.
1. Brown clay, passing into grey	3
2. Grey clay	5
3. Grey clay, mixed more or less with peat	12
4. Mossy and flaggy peat, with prostrate trees	5
5. Sandy grey clay, full of freshwater shells	6
6. Peat, with stumps of trees and numerous shells	1
7. Light-coloured and peaty sands. *Human Skeleton*, two feet from top of bed ..	10
8. Flint gravel (Quaternary), resting on Chalk	4

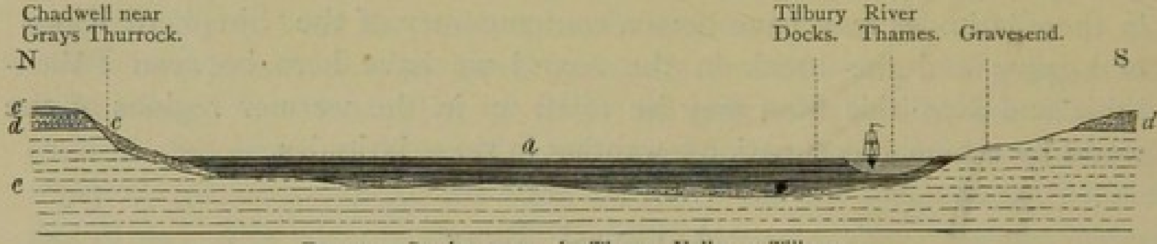


FIG. 253. Section across the Thames Valley at Tilbury.
a. Alluvial Beds. c. Low-level Drift. c'. High-level Gravel. d. Lower-Tertiary Strata. e. Chalk.

In the upper clay beds there were few or no shells; but Limnæa, Planorbis, Bythinia, Valvata, etc., abounded in the lower part of bed No. 5 and in the peat No. 6. I could not hear of the discovery of any Mammalian remains nor could I find any marine shells. The human skeleton found in bed No. 7, and 34 feet below the surface, has been described by Owen, who remarks that the peculiarities presented by the skull, such as the prominence of the frontal sinuses, the contraction and slope of the forehead, are only to be matched by low Australian and Andamanese skulls; while the size of the teeth, which were ground down flat, equals that of the Australian and exceeds that of the European. From these characters and the depth at which it was found, it is clearly the skeleton of a very ancient (but not palæolithic) man. There were no flint or other stone implements met with; but these have often been found elsewhere in the Thames Valley alluvium. (See Fig. 253.)

The upper bed of peat consisted chiefly of mosses, reeds, and grasses, with few trees; whereas the lower and thinner bed was one matted mass of wood and leaves, with the stumps of many trees standing erect,—one of them was ten feet in height. The trees appeared to be Birch, Hazel, Oak, and Alder.

Higher up the valley at Grays, three peat-levels were found, with a considerable number of the bones of Bear. Flint and stone Implements of Neolithic types are of frequent occurrence in the Alluvial beds in other parts of the Thames Valley; and whereas the palæolithic implements are always made of rocks found in England, and generally of those of the district where the implements occur, the Neolithic implements are not merely made from the local flint and other stones, but also from rocks foreign to the locality, and sometimes to this country.

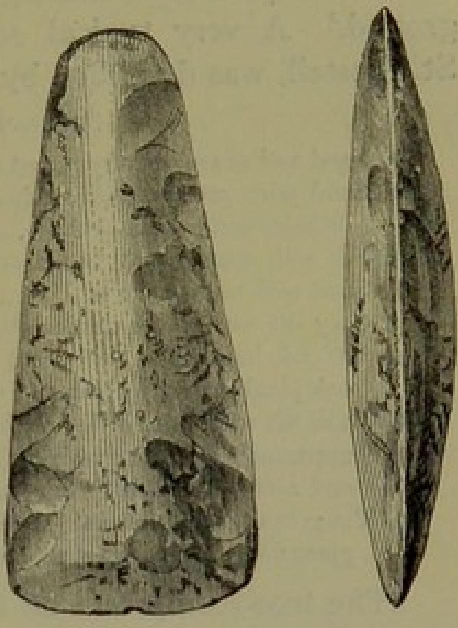


Fig. 254. *Neolithic flint Celt from Coton, Cambridgeshire*, ½ nat. size. (Evans)

The annexed figure (Fig. 254) is a common type of these implements, which in this country are generally made of flint, and, unlike the Palæolithic implements, they are often ground and polished, especially at the ends.

The Severn Valley furnishes very analogous sections. Mr. W. C. Lucy's[1] sections of the alluvial beds of the Lower Severn Valley show that below an upper bed of clay, and at a depth of from 20 to 30 feet, there is a bed of peat, representing an old forest-growth, composed chiefly of Oak, Alder, Beech, and Hazel, and attaining in places a thickness of 14 feet. One of the Oaks was quite a giant, measuring 80 feet in length as it lay, and five feet in diameter at the base. A common shell is the *Tellina solidula*, which now abounds in the lower part of the Severn. The skulls and antlers of Red Deer, and of a smaller Deer, bones and teeth of Horse, Dog, Boar, and *Bos longifrons*, occur near the bottom of the peat. One pair of antlers had been cut off by some rude implement. A well sunk near Lydney Basin, at a short distance from the Severn Valley, gave the following section:—

	feet.
1. Surface soil	2
2. Blue clay with small shells	15
3. Peat, composed of Moss, Reeds, and pieces of wood; with bones of animals ...	4
4. Fine white sand	1
5. Gravel and sand	2
6. Pebbles, sand, etc., resting on New Red Sandstone	4

Cornwall. The old stream-tin diggings in Cornwall furnish corroborative evidence. A subangular gravel, with pebbles or nuggets of tin-ore, lies under the alluvial deposits in the valleys, and this has in consequence led to the opening out of the Alluvium in a way which few other objects could

[1] 'The Submerged Forest, Holly Hazle, Shrapness;' Gloucester, 1874.

have effected[1]. A great number of these sections are given in the 'Trans. Roy. Geol. Soc. Cornwall[2].' Many of them show that the tin-ground, which now lies at a depth of from 40 to 50 feet below high-water-level, was at one time a land surface with Oaks, Hazel, Alder, etc. growing upon it, —the stumps still remaining *in sitû*, with their roots running into the 'tin-ground.' A very typical section near Pentuan Harbour, not far from St. Austell, was described by Colenso in 1829.

SECTION IN THE PENTUAN VALLEY.

	Feet.
1. Sand and gravel of very recent date	20
2. Sand with prostrate trees (chiefly Oaks), bones of Red Deer, Boar, skeleton of Whale, and human skulls	20
3. Silt with stones, sand, bones, and wood	2
4. Sand with marine shells	½
5. Grey silt with recent marine shells entire and in the position in which they lived. Wood, hazel-nuts, bones and horns of Deer and Ox, together with a narrow oak plank shaped by man, and with a barnacle attached, were also found in this bed	10
6. Dark silt with layer of leaves, hazel-nuts, sticks, and moss, very little altered and apparently *in sitû*, overlying a bed of oysters, among which were the stumps and roots of trees in their natural position, and with shells attached to them ...	2
7. Tin-ground, with rounded pieces of granite, and subangular pieces of slate and greenstone. (The trees are rooted on the surface of this bed)	3 to 10

The tree-stumps are 48 feet below high-water mark. In another place at a depth of 17 feet beneath the surface, and 22 feet below high-water, a human skeleton was found buried under a few logs of wood. No mention is made of the occurrence of stone implements in either of those sections.

The submerged forests occurring off many parts of these coasts, as well as in the Bristol Channel, belong no doubt, generally, to the age of this old submerged land-surface. The submerged forests and peat lands at the entrance of the Mersey and on the Lancashire coast, as well as those on the Lincolnshire coast, are also of much interest.

The plants and the fresh-water and fluviatile shells of the Alluvial beds are all identical with those now living in the country, although their distribution is often somewhat different. Amongst the animal remains there are found,—

Brown Bear.	Red Deer.	Urus.
Wild Boar.	Reindeer.	Short-horned Ox.
Wolf.	Roebuck.	Horse.
Beaver.	Elk.	Goat.
Otter.	Megaceros.	Dog.

Of all these animals the Red Deer is the most common. The domestic animals are of less frequent occurrence.

The foregoing sections show that in the Thames Valley the lower forest-growth is 40 feet below high-water level; in the Severn it is,

[1] All these works are now abandoned.

[2] See also Mr. Ussher, 'On the Post-Tertiary Geology of Cornwall,' *Op. cit.*, p. 40.

PLATE XVI.

QUATERNARY (PLEISTOCENE) MOLLUSCA.

Glacial. (Marine.)

1.	Panopæa Arctica, *Gould*, ...	$\frac{1}{2}$ size	*Kyles of Bute.*
2.	Mya truncata, *Brod.* (var. *Uddevalensis, Forb.*),	$\frac{1}{2}$,,	*Clyde Beds.*
3.	Saxicava rugosa, *Linn.* (var. *arctica*), ...	$\frac{1}{1}$,,	*Clyde Beds.*
4.	Pecten Islandicus, *Müll.*, ...	$\frac{1}{2}$,,	*Kyles of Bute.*
5.	Astarte borealis, *Chem.* (*A. Arctica*), ...	$\frac{1}{1}$,,	*Clyde Beds.*
6.	Tellina calcarea, *Chem.* (*T. proxima, Brown*),	$\frac{1}{1}$,,	*Paisley.*
7.	Leda Arctica, *Brod.*, ...	$\frac{1}{1}$,,	*Ayrshire.*
8.	Leda pernula, *Müll.*, ...	$\frac{1}{1}$,,	*Paisley.*
9.	Velutina lævigata, *Penn.*, ...	$\frac{1}{1}$,,	*Dalmuir.*
10.	Trophon clathratum, *Linn.* (var. *Gunneri*),	$\frac{2}{3}$,,	*Paisley.*
11.	Natica affinis, *Gm.* (*N. clausa*), ...	$\frac{1}{1}$,,	*Clyde Beds.*
12.	Littorina limata, *Lov.* (*L. rudis, Maton, var.*),	$\frac{1}{1}$,,	*Paisley.*

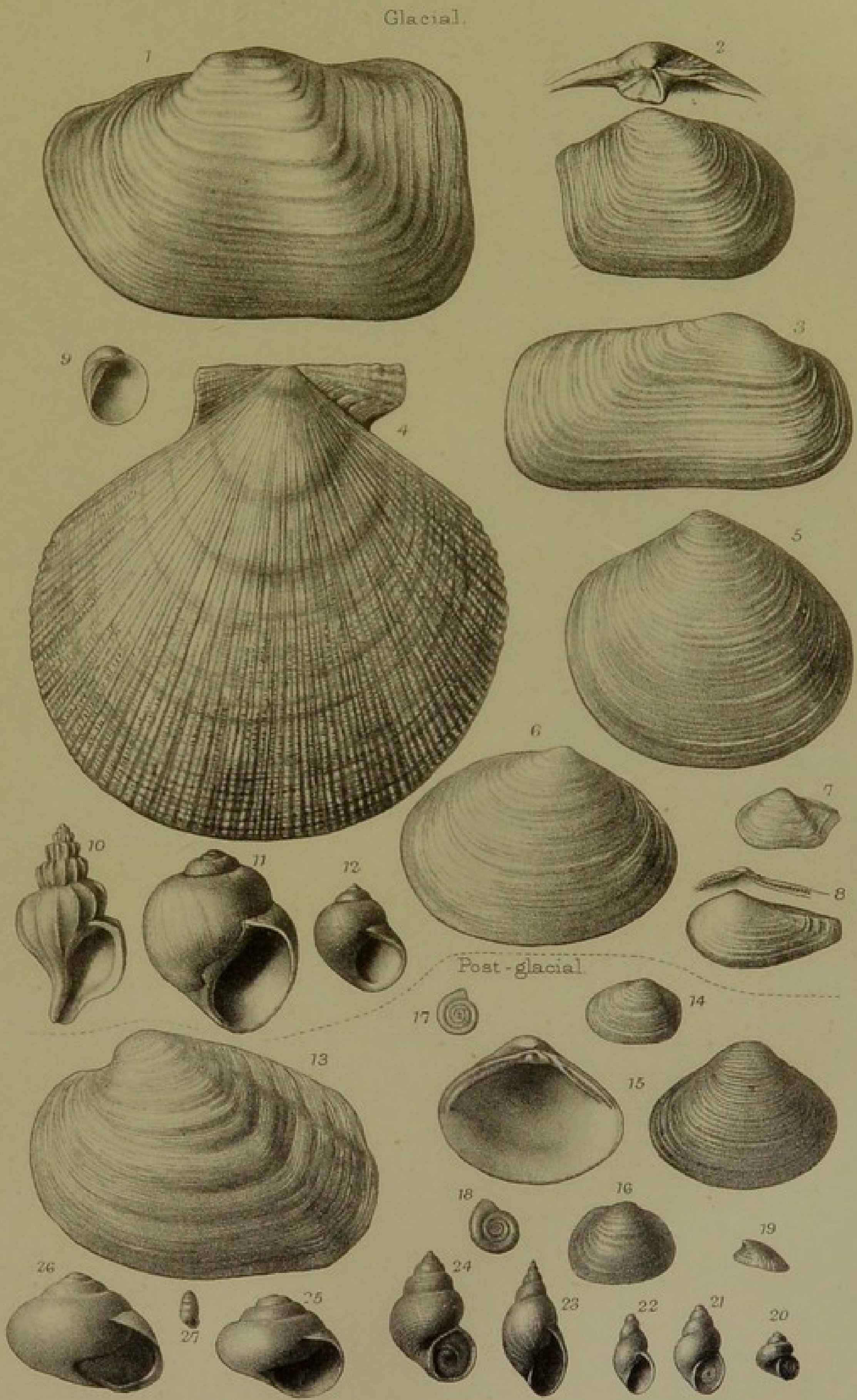
Post-Glacial[1]. (Land and Fresh-water.)

13.	Unio littoralis, *Lam.*	*Low-level Valley Drifts.*
14.	Pisidium amnicum, *Müll.*	*Valley Drifts.*
15.	Cyrena (*Corbicula*) fluminalis, *Müll.*	*Low-level Valley Drifts.*
16.	Sphærium (*Cyclas*) corneum, *Linn.*	*Valley Drifts.*
17.	Planorbis spirorbis, *Linn.*	*Valley Drifts.*
18.	Planorbis complanatus, *Linn.*	*Valley Drifts.*
19.	Ancylus fluviatilis, *Linn.*	*Valley Drifts.*
20.	Valvata piscinalis, *Müll.*	*Valley Drifts.*
21.	Bithynia tentaculata, *Linn.*	*Valley Drifts.*
22.	Succinea oblonga, *Drap.*	*Valley Drifts.*
23.	Limnæa palustris, *Drap.*	*Valley Drifts.*
24.	Cyclostoma elegans, *Drap.*	*Loess.*
25.	Helix hispida, *Linn.*	*Loess.*
26.	Helix nemoralis, *Müll.*	*Loess.*
27.	Pupa marginata, *Drap.*	*Loess.*

[1] *The greater number of these species are also Glacial.*

Plate XVI.

QUATERNARY (PLEISTOCENE) MOLLUSCA.



G. M. Woodward del. et lith.

Prestwich's Geology. II.— Clarendon Press.

according to Mr. Lucy, about 35 feet; and on the Cornish Coast as much as 48 feet. Therefore the present height of the Raised Beaches does not represent the extent of their first elevation, but is the result of a subsequent settlement, whereby some 40 to 50 feet of that rise were lost.

Supposing the old land-surface to have stood 10 to 20 feet above high-water level, this would make a difference between the original and the present level of from about 50 to 70 feet, a change of level which seems to have been very general, not only round the English Coasts, but also on the Northern and Western Coasts of France. A rise of this extent would convert a large portion of the English Channel and a considerable belt on the Eastern and Western Coasts into dry land, and gives support to the traditions respecting the former extent of land between the Channel Islands and the Coast of Normandy—a tradition also supported, as in the case of the submarine forest of Bideford Bay, by the occurrence of artificially formed flint flakes amongst the débris of the old land-surface.

Such is the result of the last of those movements which we have traced through all geological history. Continuous for long periods in the earlier times, and productive of settlements to be measured, in Cambrian and Silurian times, by thousands of feet, they have gradually diminished in intensity and power until, in the later geological times, those great slow continental movements[1] became limited to hundreds, and, in more recent times, have become reduced to, so to speak, tens of feet, or to a state of comparatively stable equilibrium, fitting the surface for the habitation of civilised Man.

[1] I am not now alluding to 'mountain movements,' which belong, as before mentioned, to a different category.

CHAPTER XXXIII.

THE CAUSE AND DURATION OF THE GLACIAL EPOCH.

GEOLOGICAL AGE ONLY RELATIVE. CAUSE OF THE GLACIAL COLD. VARIOUS HYPOTHESES PROPOSED. DR. CROLL'S ASTRONOMICAL HYPOTHESIS. EFFECTS OF ECCENTRICITY OF THE EARTH'S ORBIT. GEOLOGICAL OBJECTIONS TO THE HYPOTHESIS. ITS VALUE ON OTHER GROUNDS. ALPINE OBSERVATIONS. RATE OF GLACIER-MOVEMENT. APPLIED TO THE OLD GLACIERS. RESULTS OF THE DANISH EXPEDITION. RATE OF MOVEMENT OF THE GREENLAND ICE-SHEET. COMPARISON WITH THE OLD ICE-SHEET. ITS GROWTH COMPATIBLE WITH A COMPARATIVELY SHORT PERIOD OF TIME. ROUGH ESTIMATE OF THAT TIME. INADEQUACY OF THE PRESENT RATE OF DENUDATION. RIVER- AND ICE-ACTION AS TERMS OF COMPARISON WITH THE PHENOMENA OF THE GLACIAL PERIOD. IMPROBABILITY OF A STATIONARY CONDITION OF MAN AND THE ASSOCIATED FAUNA FOR THE LONG PERIODS REQUIRED ON THE ASTRONOMICAL HYPOTHESIS. CONTEMPORANEITY OF EASTERN CIVILISED MAN WITH PALÆOLITHIC MAN OF WESTERN EUROPE.

THE vicissitudes of climate and the measurement of geological time constitute two of the most attractive and at the same time most difficult of the problems which geologists have to consider. The question of actual time—a question so constantly asked by those unacquainted with geology—does not admit of a solution on the geological data; there are too many unknown factors; while the extreme differences in the astronomical estimates afford as yet no ground for confidence. All that can be determined with respect to age is only relative and is not measurable. We can tell the relative age of the several Formations, and may, from their dimensions and succession of life, form some rough estimate of their relative duration, but nothing beyond.

The chief attempts to define the duration of a geological period, and at the same time to assign a special cause for a special effect, have been made with reference to the Pleistocene Period, or rather to that portion of it which embraces the Glacial Epoch. To account for the extreme cold of that period various causes have been suggested,—such as a greater extent of land around the North Pole,—a change in the earth's axis of rotation,—changes in the centre of the earth's gravity,—and variations in the obliquity of the ecliptic;—but these causes have been either considered insufficient or were based on erroneous data. The theory which has of late found most general favour is that of Dr. J. Croll[1]. His views have been put forward in a manner so concise and clear, supported by so much research, and the results are so definite, that they have found very general acceptance. His hypothesis is based on astronomical conditions, and on the physical effects resulting from such conditions.

Eccentricity of the Earth's Orbit. Leverrier had established the fact that the eccentricity of the Earth's orbit varies in the course of long time. Dr. Croll further extended the calculations, and computed the periods of maxima and minima eccentricity and the longitude of the perihelion for the last 3,000,000 years, and he found that within that time there had been four or five principal periods when the eccentricity rose to a very high value, with a few subordinate maxima between. He supposes the Glacial Period to have occurred during one of the later periods of maxima, when the eccentricity was near its highest value, and when winter and summer coincided with aphelion and perihelion respectively. The result of this would be that the winter was longer than at present, and, owing to the sun's greater distance, was also colder; while the interval between the autumn and the spring equinoxes would be longer by forty-four days, and the distance of the sun from the earth would be 99,584,100 miles, whereas in perihelion it would be only 85,218,900 miles. At present the Earth's distance during our northern winter is 90,847,680 miles; but during the Glacial Period, when the orbit was at its greatest eccentricity, the distance would have been 8,736,420 miles further from the Sun.

Croll's Hypothesis. The combination of these conditions led Dr. Croll to the conclusion that the direct heat of the Sun would, during the winter-half of the year, be one-fifth less, and during the summer-half one-fifth greater than now, and that this great difference would so affect the hemisphere, whose winter solstice was in aphelion, that the climate would suffer to an approximately corresponding extent, and cause an excessive accumulation of snow and ice at the Poles. About 2,650,000 years back the eccentricity was almost at its inferior limit. A period of great eccentricity occurred about 980,000 to 720,000 years ago; and another and last such period commenced 240,000 years ago and ended 80,000 years back. It is to the latter of these that Dr. Croll would refer the Glacial Period.

It is impossible in these few pages to do justice to Dr. Croll's elaborate argument. While unable to accept all its consequences, it is difficult to imagine but that an astronomical cause of so marked a character must have had some important influence on the climate at times during the various geological periods. Astronomers have however expressed an opinion that the climate could not have been affected to the extent required

[1] 'Climate and Time in their Geological Relations,' London, 1875.

for the Glacial Epoch by changes in the eccentricity of the Earth's orbit, and physicists have contested the adequacy of the assigned physical causes [1].

Objections. I have elsewhere stated my objections on purely geological grounds to Dr. Croll's hypothesis, which would, concurrently with assigning a cause for a cold period, establish dates for the time of its occurrence, involving consequences of extreme importance respecting the Antiquity of Man. The subject is of too controversial a nature to be discussed here; but the reader will find the fuller particulars in my recent paper on this question [2]. I may, however, briefly mention two of the objections. In the three-million years for which Dr. Croll computed his tables, there were four or five occasions during which the eccentricity was as great or greater than during the Glacial Epoch proper, so that taking geological time at the 100-million years at which Dr. Croll estimates it, there should in all probability have been some 130 to 160 such periods of cold, whereas he is only able to adduce about ten instances, and of these most geologists would, I think, reject the larger proportion. The only period in geological history in which there seems reasonable grounds for supposing the existence of another Glacial epoch is the Permian, which we have already discussed (Chapter ix). But that is a question yet far from settled.

The other objection is, that, while Dr. Croll refers the Glacial Epoch proper to the eccentricity which commenced 240,000 and ended 80,000 years ago, the greater and longer eccentricity of 980,000 to 720,000 years since, which should have resulted in a greater cold and more extensive glaciation, has left no corresponding traces of such an event in the preceding Tertiary periods.

Although there are these and other objections to be urged against the acceptance of Dr. Croll's hypothesis as a sufficient explanation of the Glacial Epoch, I think it has a high value in other respects,—that it will serve to explain those minor vicissitudes of climate, of which we have so many instances in geological history, such, for example, as the cooler climate indicated by the Gelinden flora and by the Thanet Sands fauna. On the theory which best harmonises with the entire series of geological phenomena,—namely that the globe has been a slowly cooling body,—there should have been through all geological times a gradual lowering of the surface temperature; but although, on the whole, there has been such a gradual reduction, there have been vicissitudes for which the hypothesis of Dr. Croll may prove particularly applicable. The hypothesis may also prove available as a base for certain chronological data in geological history, of which we are at present deficient.

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[1] See the various papers by Professor Newcomb, the Rev. E. Hill, and others, in 'Phil. Mag.,' 'Quart. Journ. Geol. Soc.,' and 'Geol. Mag.,' 1878–1884. Dr. Croll's answers will be found in the same periodicals.

[2] 'Quart. Journ. Geol. Soc.,' vol. xliii. p. 393.

This brings us to the second question—that of the dates to be assigned to the Glacial Period. The terms of 160,000 years for the Glacial and 80,000 years for the Post-glacial epochs proposed by Dr. Croll, met with no objections from those geologists who hold Uniformitarian doctrines, by some of whom in fact these terms were considered too short. Founding their belief on the present rate of denudation and existing conditions of glaciers in the Alps, this probably could hardly be otherwise[1].

Alpine Glaciers. Until lately, the only definite information we had respecting glacier action was derived from Alpine experience. The observations of Agassiz, Forbes, Tyndall, and others had made us acquainted with the growth, decay, and rate of motion of the Alpine glaciers; but until lately little was known in respect of the Scandinavian and Greenland glaciers. The centre of the Mer de Glace was found to advance in the month of July at the rate of 33 inches in the twenty-four hours, the Aletsch glacier in August at 19 inches; or if we take other more general observations extending over a longer period, we have the following results:—

Glacier du Bois—Annual mean of 2 years movement		... ...	364 feet.
Rhone Glacier—Annual mean of 7 years	„	... ...	366 „
The Aar Glacier—Annual mean of 14 years	„	(Hugi's hut),	338 „

This gives an average annual rate for these glaciers of 355 feet. The advance and retreat of the terminal front of a glacier are of course not immediately connected with this continuous motion of the great body of ice, but depend on the climatal conditions of the year. In the cold summers of 1816 and 1817 there was a general advance of all the Swiss glaciers, whilst since 1856 there has been a general retreat. Usually the loss or gain is small, but in some years it is considerable. In one year the Glacier of Grindelwald

[1] The subject is discussed at length by Lyell in the 'Principles of Geology,' 10th edit., chapter xiii. After considering the last periods of maximum eccentricity, he remarks that these 'would not be sufficiently distant from our era to afford time for that series of Glacial and Post-glacial events which we can prove to have happened since the epoch of the greatest cold. These events relate to changes in the level of the land in opposite directions, as well as the excavation of valleys, and variations in the range and distribution of aquatic and terrestrial animals, all of which take place at so slow a rate, that 200,000 years would not be sufficient to allow of the series of changes with which we are acquainted. I agree, therefore, with Mr. Croll, that, if the date of the most intense glacial cold can be arrived at by aid of a very large eccentricity, it would be a more probable conjecture to assign C. (dating 850,000 years back) than B. (dating 210,000 years back) as the period in question.'

Sir John Lubbock in 'Prehistoric Times,' 2nd edit. p. 403, inclines to the shorter period of about 200,000 years back.

Dr. John Evans in his 'Ancient Stone Implements of Great Britain,' chapter xxv, in an excellent summary on the Antiquity of the River-Drift and of Man, without committing himself to those exact dates, expresses his conviction that the period must have been one of very great length. Looking only at the denudation of one small area as involving a period of not less than 10,000 years, he remarks that the time required for the denudation of the whole tract, as it presented itself at the commencement of the Quaternary period, must be immensely remote; it must have been, he thinks, many times 10,000 years, and the mind is almost lost in amazement at the vista of antiquity displayed.

advanced 100 feet, while the Glacier of Lys advanced nearly 1000 feet in six years.

But the most remarkable case is that of the Yernagt glacier in the Tyrolese Alps, which is exceptional in that it advances by fits and starts. Between 1843 and 1847 the ice from this glacier covered the valley below to the length of 1264 mètres, which gives a mean annual rate of 870 feet, while the thickness of the mass of ice near its extremity exceeded 500 feet. Another glacier in the same range advanced, after all oscillations, above a mile in a century. On the other hand, the Rhone glacier between 1856 and 1877 retreated nearly half-a-mile, or on an average 116 feet annually; whilst between 1870 and 1877 the retreat extended for a distance of 400 mètres, or a mean of 187 feet per annum, the greatest retreat being between the years 1870 and 1874, when it amounted to 250 mètres, or a mean of 205 feet per annum. In the Valley of Chamouni the Glacier du Tour retreated 320 mètres in the eleven years between 1854 and 1865, or at the rate of about 155 feet annually; and on the Glacier des Bossons the surface of the ice was lowered 260 feet in twelve years, while the mean annual ablation of the Swiss glaciers is estimated at about 10 feet only.

Here, therefore, seasonal fluctuations alone are attended by alternate advances and retreats of the glacier front of not less in both ways, on a mean of the major instances, of from 200 to 300 feet per annum. If these mere seasonal fluctuations are attended by changes of this extent, it would follow that with the secular increase of cold during the Glacial epoch, the rate of progress must have considerably exceeded these limits. But even at that rate, taking a mean of 250 feet, the longest of the old Swiss glaciers,—namely that of the Rhone, which then had a length of 240 miles,—might have been formed in 5000 years. This, however, is assuming the absence of most important seasonal retardations and fluctuations, which is not possible. Allowances have to be made for warmer seasons and temporary retreats of the ice, and also for the fact that the old glacier did not move on the steep inclines of Alpine valleys, but traversed the small incline of a great river-plain. On the other hand, we have to take into account the circumstance that the present seasonal changes give no adequate measure of the growth of ice under the more extreme glacial conditions of that epoch. Nothing positive can therefore be founded on this case, though it may serve to show the possibility of a more rapid rate of progress of the old glaciers than is required by the estimate of time hitherto adopted.

We have now, however, in Arctic regions truer and more adequate terms of comparison in the great ice-sheet of Greenland. Already in 1876, Professor Helland [1] showed that the rate of flow of the Greenland glaciers

[1] 'Quart. Journ. Geol. Soc.,' vol. xxxiii. p. 142.

was much more rapid than those of Switzerland. The Jakobshaven glacier, notwithstanding its small slope of only half a degree, he found to advance its front at the rate of 50 to 60 feet a day. The flow of the glacier of the Fjord of Torsukatak, which is nearly five miles broad, give a rate of from 12 to 33 feet daily. Taking the average rate of the three glaciers on which Professor Helland made observations, the average discharge of the ice was 23 feet in the twenty-four hours. These observations, however, were made in the summer months, and were only of a few days' duration, so that the annual rate remained uncertain.

The Greenland Ice-Sheet. Since then the members of a Danish scientific expedition have completed a most important exploration of the Greenland ice, and a short summary of the work has recently been given by Dr. Rink[1]. Their observations fully confirm those of Professor Helland, and show that the motion of the inland ice may be compared to an inundation. It was found that there is a general movement of the whole mass of the ice from the central regions towards the sea, and that it concentrates its force to comparatively few points in the most extraordinary degree. These points are represented by the so-called ice-fjords, through which the annual surplus of ice is carried off and discharged in the shape of icebergs.

The velocity of the ice was measured in seventeen glaciers, the measurements being repeated during the coldest and the warmest seasons; and it was found, remarkable as it may seem, that the movement was not influenced by the seasons. The great glacier of the ice-fiord of Jakobshaven, which has a breadth of 4500 mètres, was rated at 50 feet a day. One of the glaciers in the ice-fiord of Torsukatak has a movement of between 16 and 32 feet daily. The large Karajak glacier, about 7000 mètres broad, proceeds at the rate of 22 to 38 feet in the twenty-four hours; and another in the fiord of Jtivdliarsuk, 5800 mètres broad, at 24 to 46 feet. The conclusion at which the Danish Corps arrived was, that the glaciers which produce the bergs move at the extraordinary rate of 30 to 50 feet a day throughout the year; so that in the ice-fiord of Torsukatak, a mass of ice nearly 5 miles wide and 1¾ mile long must pass out annually; that the Karajak glacier discharges a mass of above 2 miles in length and 4⅓ miles in breadth; and that in the huge ice-fiord of Jakobshaven, a length of above 3 miles, with a breadth of nearly 3 miles of ice, is discharged annually. There are also other ice-fiords of far greater breadth than those, such as the Humboldt glacier, which is 60 miles broad.

Rate of Motion. Until the rate of motion of all the glaciers has been ascertained, and we know the relation of their totals to the breadths

[1] 'Trans. Edin. Geol. Soc.,' vol. v. p. 286 (1887).

of the intervening 'Nunataks[1],' no definite measure of the total volume of annual surplus ice can be established; but for our general purpose some approximate idea may be formed. Taking the average rate of movement of the great glaciers at 35 feet daily and the discharge of ice at 2½ miles of ice annually,—together with the proportion which the glaciers bear to the extent of coast,—the average of the fringe of ice which would pass off from the land may be estimated at ⅛ of a mile in width annually, so that a breadth of 1 mile would take eight years to pass. Assuming a proportion at more extreme limits, then it might take twelve years. In the one case a sheet of ice 100 miles long and of a width equal to the length of the central ridge would require 800, and in the other 1200 years for its growth; or applying these measures to the old ice-sheets, and taking the length of the maximum radius of the bodies of ice, of which the Canadian highlands and the Scandinavian mountains formed the centre, at 500 miles, the time required for the prolongation of this length of ice-sheet would be in the one case 4000 and in the other 6000 years.

On the other hand, an allowance has here again to be made for seasonal fluctuations, which would retard the ice-flow for greater or less periods; and though we cannot suppose these minor quantities to be in excess of the main integer, still no doubt very considerable allowances must be made for such contingencies.

These intervals, therefore, although they may involve considerations respecting hundreds of years, must have been subordinate to the general progress of the ice-sheet, and are therefore scarcely likely to involve questions relating to many thousands of years. It is to be observed also that there is no evidence in North America of an interglacial period in the sense of the one supposed to have existed in Europe.

Whilst there are these reasons for prolonging the duration of the Glacial Epoch, there are other factors in the question which tend to shorten it. It may be a question whether or not the rainfall was then greater than now. At present in Greenland it is small, apparently under 20 inches, while in the North-American old ice-area it is not less than 40 to 45 inches annually. Possibly the precipitation in the Glacial Epoch was even larger; for the Florida promontory, which now deflects and contracts the Gulf-stream, was at that time considerably smaller (Vol. I, p. 245), the coral-reef of which it consists not having then extended so far south. Consequently, that channel having been wider, a greater volume of water flowed through it; and this larger body, thus carried into the North Atlantic, and retaining therefore its heat longer than it does now, may, in consequence of its increasing the saturation of the incumbent air, have materially affected

[1] Mountain-tops of the coast-range rising above the general ice-sheet, and intervening between the several glaciers and fjords.

the precipitation of rain and snow both in North-eastern America and North-western Europe.

The growth of an ice-sheet is not, however, dependent only on the rainfall. The experiments of MM. Dufour and Forel have shown that when the temperature of the air on the Rhone glacier varied from 41° to 52° F. there was a condensation of moisture equal to 150 cubic mètres of water for a square kilomètre in the twenty-four hours.

Chronological Value. The Greenland observations therefore tend to show that the growth of the old ice-sheets might have been at the rate of 1 mile advance in 8 or 12 years, *minus* the retardation due, 1st, to friction, irregularities of surface and small gradients; 2ndly, to seasonal changes of temperature (including the so-called Inter-glacial periods); *plus*, 1st, a more rapid growth due to progressive secular refrigeration, and 2ndly, to increased precipitation and condensation. The one possibly known quantity gives from 4000 to 6000 years. Of the unknown quantities we can at present but form a distant idea. We can only feel assured that they were, in all probability, subordinate to the known quantity. My own opinion, based on the facts here named, is—that the time required for the formation and duration of the great ice-sheets in Europe and America (the Glacial Period) need not, after making all allowances, have extended beyond 15,000 to 25,000 years, instead of the 160,000 years or more which have been claimed.

The adoption by some of a term of 80,000 years for the Post-glacial period has been very much the result of the belief that no shorter time would account for the excavation of the valleys supposed to have been formed during this period on the assumption of a 'uniformitarian' rate of denudation. This rate, based on observations made at the present time, always seemed to me open to grave objections, and in this belief subsequent experience has confirmed me. Dr. Croll, who, with others, adopts the generally-accepted rate of denudation, namely, one foot of rock or soil removed off the general level of the country during 6000 years, remarks at the same time—'if the rate of denudation be at present so great, what must it have been during the Glacial epoch? It must have been something enormous.'

Nevertheless, his arguments and those of the geologists who adopt his views proceed, while insisting on the importance of ice-action, on the assumption of the 'uniformitarian' rate. But it is no more possible to judge of the rate of denudation during the Glacial period by the river- and ice-action of the present day, than it was of the rate of flow of the Greenland ice by modern Alpine experience. The enormous pressure and wear of ice 2000 to 6000 feet thick in contracted valley-channels, especially in fiords, where, as for example in Greenland, it stood 1800 to 2000 feet higher than now; the powerful disintegrating effects of extreme cold on rocks; the annual action of ground-ice in rivers, and of the sweeping and devastating floods, resulting from the melting of the winter's snow and surplus ice, combined to produce results of which it is impossible to judge by the moderate work of these temperate latitudes. We must go to high northern latitudes to find any terms of comparison, and there much is now wanting to complete the parallel.

Duration of the Glacial Epoch. In this country and the North of France broad valleys have been excavated to the depth of from about 80 to 150 feet in Glacial and Post-glacial times. Difficult as it is by our present experience to conceive this to have been effected in a comparatively short geological term, it is equally, and to my mind more, difficult to suppose that Man could have existed 80,000 years or more, and that existing forms of our fauna and flora should have survived during 240,000 years without modification or change.

For the reasons before given I think it possible that the Glacial Epoch —that is to say, the epoch of extreme cold—may not have lasted longer than from 15,000 to 25,000 years, and I would for the same reasons limit the time of the so-called Post-glacial period, or of the melting away of the ice-sheet, to from 8000 to 10,000 years or less. This might give to Palæolithic Man, if we can be allowed to form a rough approximate limit, on data yet very insufficient and subject to correction, no greater antiquity than perhaps about 20,000 to 30,000 years; while, should he be restricted to the so-called Post-glacial period, his antiquity need not go further back than from 10,000 to 15,000 years before the time of Neolithic Man [1].

Looking at the facts before mentioned—that most of the species of our existing marine and land fauna and flora appeared in true Pre-glacial time, that is to say, contemporary with the Forest-bed-group, and that their characters are unaltered,—that the great extinct Mammalia of that time have left no descendants, but have merely died out as a consequence of the great changes of climate and conditions,—and to the difficulty of conceiving that Man could have existed for a period of 80,000 to 100,000 years without change and without progress—looking, I say, at these facts, it seems to me that the shorter estimate of time is the one more in accordance with all the conditions of the problem.

This view of the question also brings the geological and anthropological data into closer relationship. Palæolithic Man in North-western Europe disappeared with the valley-gravels. With the alluvial and peat-

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[1] This must only be considered a very preliminary attempt not to define with precision, but rather to reduce to narrower limits, these geological epochs. The extreme antiquity of even 80,000 years (not to speak of the estimate of 150,000 to 200,000 years) assigned to Man, seems to me based on such very inapplicable evidence, and has received so wide an acceptance, that I think it desirable at this stage of the subject to express, possibly rather prematurely, the result of my own observations and belief.

beds Neolithic Man appeared after an unascertained, but clearly not very long interval geologically speaking. In Europe we are unable to carry back his presence beyond a period of from 2000 to 3000 years B.C. But already in Egypt, and in parts of Asia, it is proved that civilised communities and large states flourished before 4000 B.C. Civilised Man must therefore have had a far higher antiquity in those countries, and probably in Southern Asia, than these 4000 to 5000 years; so that comparing Europe and Asia, it is possible that the two periods may have overlapped, and that while Man had advanced and flourished in a civilised state in the East he may here in the West have been in one of his later Palæolithic stages.

CHAPTER XXXIV.

THEORETICAL QUESTIONS: CONDITION OF THE EARTH'S CRUST.

MOBILITY OF THE EARTH'S CRUST. ITS PRESENT STABILITY. EFFECT OF INTERNAL TIDES. THICKNESS OF THE CRUST. DIVERGENT OPINIONS. GEOLOGICAL OBJECTIONS TO A THICK CRUST. THE LATER MOVEMENTS OF THE CRUST. COMPARISON WITH A MOVABLE PLATE RESTING ON A YIELDING SUBSTRATUM. PROOFS OF RECENT ELEVATION. OTHER CAUSES OF CHANGE OF LEVEL. VOLCANIC EJECTIONS. EFFECTS OF EXTRAVASATION. GRAND SCALE OF SECULAR MOVEMENTS. CONDITIONS CORRESPONDING WITH THE GEOLOGICAL PHENOMENA. VISCIDITY OF THE MOLTEN MAGMA. ITS COMPRESSIBILITY. RESULTS OF TRANSFERENCE. ORIGIN OF MOUNTAIN-CHAINS. SECULAR REFRIGERATION. LATERAL PRESSURE. OTHER CAUSES. VARIED EFFECTS OF CONTRACTION. CONTINENTAL AND MOUNTAIN ELEVATION. OCEAN BASINS. EFFECTS OF DEEP COLD CURRENTS. EFFECTS OF A GENERAL REFRIGERATION IN CAUSING GREATER PRESENT STABILITY.

Mobility of the Earth's Crust. The dominant physical feature which cannot fail to strike every one who has followed the sequence of geological history, as recorded in the successive stratigraphical formations, is the constant change in the relative distribution of land and water,—the long periods of slow subsidence,—the continental elevations,—the enormous faulting of the strata,—their compressed foldings,—and colossal ridging in Mountain-chains. Whatever may be the present rigidity of the Earth's crust, it will be obvious that that rigidity has not been of long duration,—that in early geological periods its mobility was excessive,—that down to a very late period it has been considerable,—and that even now it has not entirely ceased, although its manifestation is on a comparatively small scale, and in general of extreme slowness.

It will further be evident from the gradual and general increase of temperature with depth, that a high internal temperature must exist at no excessive depth. Down to the depth of from 40 to 60 feet, the surface of the Earth is subject to periodical changes of temperature, dependent upon the solar heat. The differences are at their maximum near the surface, and gradually decrease with the depth, so that in these latitudes at a depth of about 50 feet a line of invariable temperature (being that of the mean annual temperature of the surface) is reached. Below that point it is proved, beyond dispute, that the temperature constantly increases with the depth at the rate of about 1° F. for every 45 to 50 feet, so far as observation has been carried, that is to rather more than 4000 feet. The exact rate depends on varying hydrometric conditions and conductivity.

With a continuance of this increasing heat a depth must eventually be reached at which there will be a temperature equal to that of boiling water, and at a greater depth (whatever that may be) we shall have a temperature equal to that of rock-fusion at the surface, though the pressure at those great depths may affect the conditions of fluidity, and introduce questions of viscosity and increased solidity, which must be taken into account.

Taking the rate of increase at 48 feet for 1° Fahr.[1] and a mean surface-temperature of 49° Fahr. (about that of London), the following will be the heat at various depths:—

Depth.		Temperature.		
0 feet	...	49°	Fahr.	Mean annual surface temperature.
50 "	...	49°	"	Line of permanent uniform temperature.
500 "	...	58.4°	"	
1000 "	...	67.8°	"	
7824 "	...	212°	"	Boiling point of water.
34752 "	...	773°	"	Critical point of water (?).
150,000 "	...	3174°	"	Approximate fusion-point of rocks.

Although there may be differences of opinion on some of the collateral issues, there can be little doubt of the important fact of the existence of an internal source of heat, and that the earth is a cooling body. On this point physicists and geologists are now agreed; also that the Earth was originally in a fluid state, and that the formation of the solid crust, with all its subsequent changes, is due to secular refrigeration.

It is also supposed that beneath the chilled and solid crust of the Earth there is a molten magma, which in past times welled out in frequent floods, and still rises to the surface spasmodically through small and special vents, as manifested by the phenomena of volcanic action. The points on which there is a difference of opinion are the thickness of that crust and the condition of the interior nucleus.

Its Present Stability. On these questions geologists and physicists hold, from their different stand-points, divergent views. Physicists have shown that the present stability of the Earth's surface is clearly incompatible with the original hypothesis of a thin crust resting on a nucleus altogether molten and fluid; but it is equally difficult to reconcile certain geological facts with the hypothesis of a globe solid throughout, or even of a very thick crust. Mr. W. Hopkins[2] came to the conclusion, on considerations

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[1] There are differences of opinion as to the exact rate of increase. See a paper by the Author in 'Proc. Roy. Soc.,' vol. xli.

[2] 'Report, British Association for 1847,' p. 33.

connected with 'Precession and Nutation,' that the Earth's crust could not have a thickness of less than from 800 to 1000 miles, and that it might even be much more. The data on which this conclusion was based were contested, however, by M. Delaunay; and Mr. Hopkins's argument has since been generally abandoned by physicists, although his main contention as to the Earth's solidity is on other grounds still maintained by them. Sir William Thomson concludes that the Earth is on the whole solid, and that its rigidity cannot be less than that of steel; for, were it less, the joint action of the sun and moon would cause tides in the fluid nucleus, accompanied by a deformation of the crust, that would largely influence the actual phenomena of the ocean tides[1].

Effect of Internal Tides. On the supposition that a molten nucleus underlies a superficial crust, Sir William Thomson says that the solid crust would yield so freely to the deforming influence of the sun and moon, that it would simply carry the waters of the ocean up and down with it, and there would be no sensible tidal rise and fall of water relatively to land.

The phenomena of the tides have not, however, been determined with sufficient accuracy to settle definitely the moot question whether the rigidity of the crust is perfect, or whether it yields to some very small extent. Therefore, while on this ground alone the conclusions cannot be accepted in their entirety in consequence of the uncertainty of the data, there are, on the other hand, certain geological phenomena, volcanic phenomena among the rest, which are not only incompatible with an entirely solid globe, but which would seem to be explicable only on the hypothesis of a thin crust and a slowly yielding viscid substratum. Of course it is also open to consideration whether a crust and substratum of this nature would not, under certain conditions, offer sufficient resistance to produce a *quasi*-rigidity such as would accord with the physical requirements.

While the more extreme views relating to the fluidity of the nucleus are evidently inadmissible in face of the present, at all events, very great rigidity of the earth, there are nevertheless a number of geological phenomena which cannot be explained on the hypothesis of a globe solid throughout, and no hypothesis can hold good which does not equally satisfy geologists and physicists. Whichever we adopt, we have to recollect the final test of its truth must depend on the concordance of calculation with fact.

It is certain that as yet the application of mathematical formulæ to geological problems has not been attended with very satisfactory results. There is a want of elasticity in the method, and generally a want of suffi-

[1] 'Trans. Roy. Soc. Edinb.,' vol. xxiii; Address to Section A, Meeting of the Brit. Assoc. in Glasgow in 1876, p. 5; 'Trans. Geol. Soc. Glasgow,' vol. vi. part i: see also Thomson and Tait's 'Treatise on Nat. Phil.,' and Professor G. Darwin's several papers in the 'Phil. Trans.'

cient knowledge of geological details on the part of the physicist, which too often render the results of such investigations inconclusive[1]. Nor do physicists themselves at all agree in their conclusions. Delaunay, Haughton, Hennessey, Fisher, and Mallet have questioned the conclusions of Hopkins, Sir William Thomson, and others, on the theoretical grounds. Here, however, we have only to consider on purely geological grounds the reasons in favour of a thin crust, and against the hypotheses of a solid globe or a very thick crust.

Reasons for a Thin Crust. The principal phenomena in proof of a fluid substratum, and of a crust of no extreme thickness, briefly stated, are[2]—1st. The flexibility of the crust as exhibited in the uplift of mountain-chains, and in the elevation of continental areas. 2nd. The rate of increase of temperature with the increase of depth from the surface. 3rd. The volcanic phenomena of the present day, and the welling-out of the vast sheets of igneous rocks during late geological periods.

It is important to note that not only has mountain-elevation gone on through all geological time, but that many, if not most, of the great mountain-chains have been raised during the latest geological periods (see Vol. I. p. 296 *et seq.*), as for instance,—

1. The elevation of the Pyrenees, which, although commencing in Palæozoic times, attained its maximum intensity and development in Oligocene, while minor movements continued to Miocene times.

2. The main elevations of the Rocky Mountains, and of the greater part of the Andes, took place during the Early Tertiary and antecedent periods; but they were raised to their present height so late as in Miocene and Pliocene times.

3. Although considerable elevations of the Himalayas are of Pre-Tertiary date, the special great Himalayan disturbance is of Post-Eocene age; while in the Sub-Himalayan ranges, the great disturbances are of Post-Pliocene date.

4. The elevation of the main axes of the Alps (although, like the others, beginning earlier) took place in Miocene times, and was prolonged to the Pliocene period, if not to Quaternary times.

It is only necessary to look at any good modern[3] section of a mountain-chain to see the enormous amount of compression and contortion the strata have invariably undergone, and the succession of folds of vast magnitude into which they have been thrown. In the Alps there are seven, if not more, of these great folds. In a straight line across they measure about 130 miles; but, if the strata were stretched out in the original planes, it is estimated that they would occupy a space of about 200 miles (see Vol. I. p. 359 and Pl. p. 304). Professor Le Conte states that the Coast-range of California consists of at least five anticlines, and

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[1] See Huxley's Presidential Address to the Geological Society in 1869; and Wadsworth in the 'American Naturalist,' June to August, 1884.

[2] I here follow the line of argument given at greater length in my paper on Underground Temperatures in the 'Proc. Roy. Soc.,' vol. xli. p. 158.

[3] The older sections fail to show the real order and meaning of the compressed strata.

as many synclines, so closely compressed that a width of 15 to 18 miles of horizontal strata has been reduced to one of six miles.

A Yielding Substratum. It is difficult to see how these corrugations of the Earth's crust are to be accounted for, unless we assume that the crust rests on a yielding substratum, and that of no great thickness. For if the earth were solid throughout, the tangential pressure would result not in distorting or crumpling, but in crushing and breaking. As a rule no such results are to be seen, and the strata have, down to the time of the youngest mountains, yielded, as only a free surface-plate could, to the deformation caused by lateral pressure. Freedom and independence of motion are self-evident in those wonderful contortions and inversions of mountain strata, and for such results a yielding bed, on which the crust could move as a separate body, was necessary. Nor is evidence wanting that such a yielding plastic bed did exist, for protruding through the central axes there are commonly masses of crystalline rocks, which must then, or shortly before, have been in a viscid state; or else the strata are penetrated by dykes and veins of igneous rocks indicative of a greater fluidity of the matter underlying the solid base.

Let us suppose not entire solidity, but a crust of 800, or even half 800 miles thick. What would be the magnitude of a mountain-chain resulting from the compression and upthrow of such a mass of rock? Where have we evidence in even the latest of our mountain-chains of the existence of such masses? Nowhere do the disturbed and tilted strata point to a mass more than a few miles thick, for the whole of the sedimentary and metamorphic rocks are often uptilted, together with a portion of the molten rocks on which they rested. Had the crust the more excessive thickness suggested by physicists, we should have had mountains, if not of greater height, at all events of greater breadth; for, if a solid plate of this kind were broken and the fractured edges turned up by reciprocal pressure in presence of a viscid but resisting material beneath, the width of the protruding mass would bear a definite relation to the thickness of the plate. If, on the other hand, the plate is sufficiently pliable to yield without fracture and bend into folds, the height of the arch and the width across the fold will, in like manner, be proportionate to the thickness of the plate. So far from a shell of 800, or 400, or even of 50 miles thick, would it not rather appear that a crust of 30 miles is even in excess of what the height and breadth of any mountain-chain would, on this finding, indicate?

Proofs of Recent Elevation. Other phenomena likewise point to a yielding substratum, although the deformation may not have resulted in the fractures and contortions involved in mountain-formation. Thus, South-eastern England, a large portion of France, great part of Spain and Italy, and the whole of Central Europe, have, since the Eocene period, undergone movements of elevation *en masse*, with little disturbance to the strata, over large areas; and these movements have been prolonged down to Miocene and Pliocene times.

The presence of shells of recent species at certain elevations in Central England and Wales, as described in Chapter xxix, proves that those areas have undergone an elevation of not less than 1400 to 1500 feet after the inset of the Glacial Period. Ireland and Scotland have undergone changes little less in the same period; and so likewise has the North American Continent. The rock of Gibraltar has been raised 1400 feet or more within the same or a later period. The *massif* of Scandinavia and the long coast-lines of the Pacific side of South America have been raised 500 or 600 feet or more during the life of existing species of Mollusca. Over portions of the Pacific Basin, islands have been raised 200 to 300 feet or more in quite recent times; and the coasts of Arctic America and Asia exhibit conclusive evidence of similar recent elevation. These movements of elevation, which bring us to the threshold of the present times, link on without break in the latter areas (and many others might be named) with the changes of level which some of those areas are still undergoing.

Other Causes of Change of Level. Changes of level have been ascribed by some writers to changes of temperature at depths, caused by the shifting upwards of the underground isotherms, in proportion as the strata have increased in thickness by the successive addition of fresh sediment. This, which was suggested by Babbage and Herschel, may be a true cause under certain conditions of thick accumulation of strata; but must necessarily, as the expansion of rocks by heat is so small, be limited to moderate vertical displacement, and fails to explain the greater changes of level to which we have just referred; for neither in the Old nor in the New World do the later Tertiary strata exceed, as a rule, a thickness of 1000 to 4000 or 5000 feet. This might shift the isotherms and cause a rise of from 20° to 100° Fahr. But even supposing this were to affect a mass of rock, say 100,000 feet in depth, the result would only be to increase its dimensions vertically from 10 to 100 feet. This also is on the assumption that the crust at that spot remains stationary; but if, whilst the accumulation of strata proceeded, the area itself, as has usually been the case, subsided, the only effect of expansion of the mass, unless it all took place at once after the deposition of the overlying strata was ended, which is impossible, would be *pro tanto* to diminish the rate and extent of subsidence. In Glacial and Post-Glacial times the sedimentary matter deposited was still less important than in Tertiary times.

Volcanic Ejections. A third objection to a thick crust is the difficulty of reconciling such a condition of things with the effects of volcanic action. It would seem impossible for a column of lava to traverse a crust 800 to 1000 miles thick, not only because of the enormous pressure required, but because the loss of heat in such a length of passage would be so great as probably to cause the lava to lose its fluidity and consolidate before it could reach the surface.

To meet this difficulty, Mr. W. Hopkins suggested that the solid crust contained, at various depths beneath the surface, cavities filled with fluid incandescent matter, either entirely insulated, or perhaps partially communicating in some cases, and that in these subterranean molten lakes the volcanic foci originate. But this is not compatible with the singular uniformity, as a rule, of the volcanic rocks over the whole globe. Besides, the enormous outwellings of basaltic and volcanic rocks, which took place at intervals during the Tertiary period and continued down to Quaternary times, afford evidence of the existence of a fluid magma underlying the solid crust, co-extensive not only with the existing volcanic outbursts, but also with the older eruptions; thus spreading the volcanic phenomena over areas so large and so numerous that it is difficult to conceive that each area formed a separate and an independent local igneous centre.

In this country the great basaltic plateau of the North of Ireland is 400 to 800 feet thick, and extends over an area of about 1000 square miles; those of Western Scotland are of about the same extent, and it is certain that both had, before the coast-denudations, a much wider range, if the two were not continuous. In Central France there is a still wider basaltic area of yet more recent date. There are others of great extent in Hungary and in Central Italy. (See Map.) They cover also large tracts in Asia Minor, Africa, New Zealand, Australia, and America. We may confine ourselves to the grand plateaux of Central India and North-West America.

In India the plateaux stretch for a distance of 500 to 600 miles from north to south, and 300 to 400 miles from east to west, covering, according to the reports of the Indian Survey, an enormous area of not less than 200,000 square miles[1]. They have a general thickness of from 2000 to 3000 feet; and it is estimated that the total thickness of all the beds amounts to not less than 7000 feet. They are of late Cretaceous or early Eocene date, and consist of a succession of beds, spread, doubtlessly, over a long period of time.

In North America vast sheets of basaltic rocks form the high plateau of Utah, while on the Pacific slopes, immense regions have been flooded by outpourings of lava from fissures at successive times from the close of the Miocene down to the Quaternary period. In Columbia, these basaltic rocks have a thickness of from 1000 to 3000 feet, and in parts of Colorado of not less than 4000 feet; and they stretch over a tract some 700 to 800 miles in length by 80 to 150 miles in width, and cover 100,000 to 120,000 square miles of surface.

Effects of Extravasation. If these vast erupted masses had

[1] 'Manual of the Geology of India,' chapter xiii.

been derived from local molten lakes at moderate depths, the extravasation would have caused a diminution in these subterranean reservoirs, which, as the loss could not be made good by drafts from adjoining areas, must necessarily have led to a caving-in and subsidence of the crust above these lakes proportionate to the mass of the extravasated matter. But so far from this being the case, the areas of these great basaltic out-wellings are almost always areas of elevation. The basaltic area of the Deccan forms great plateaux, attaining a height of between 4000 to 5000 feet; and, although the intercalated sedimentary strata are mostly of land and fresh-water origin, there is reason to believe, from the circumstances that on the borders of the same district some of the associated beds contain estuarine remains, that the area was, immediately prior to the eruption, not much above the sea-level.

In America also the basaltic plateaux rise gradually to heights of from 2000, 3000, and 4000 feet, and in some cases even attain the height of 11,000 feet or more, and these have been raised to their present height during Tertiary and Quaternary times.

It is impossible to attribute the elevation of these vast flattened domes to any of the secondary causes before named. The difference of level is too great. These areas of eruption are areas of elevation—not as in mountain-chains by lateral squeezing and an upward thrust along narrow anticlinal lines, but by elevation *en masse* of broad portions of the earth's crust, possibly accompanied by fracture, but without any material contortion. According to Darwin, while the great coral areas of the Indian and Pacific Oceans have long been areas of subsidence, the adjoining volcanic areas have been areas of elevation.

The slow secular upheaval of the vast tracts of Arctic lands on the shores of North America and Asia—an area of elevation so extensive that it embraces almost all the land bordering the Polar seas—forms an imposing spectacle. It has in comparatively modern times resulted in a rise of from 100 to 400 feet above the present sea-level; whilst it is still, in our own times, in visible action over a superficial area extending in some directions for thousands of miles.

Conditions to correspond with the Phenomena. To produce the effects here described, neither a perfectly fluid substratum nor an entirely molten nucleus is required. The hypothesis most compatible with the geological phenomena is that of a central solid nucleus with a molten yielding envelope—not fluid, but viscid or plastic; nor is it necessary that this magma should be of any great thickness; but a thin crust is, it seems to me, an essential condition. The relative proportions of the two are questions for physicists. The late Professor Roche[1] attempted a solution

[1] 'Comptes Rendus' for August, 1861, p. 364.

based on the astronomical and physical conditions of the problem. Assuming the earth to consist of a solid centre with a density of about 7.0, and of an outer layer consisting of a fluid substratum with a solid crust, and having a mean density of 3.0, he found that the two outer layers should have together a maximum thickness not exceeding one-sixth of the earth's radius, or 660 miles, but he left the question of their possible *minimum* thickness open to other considerations.

On geological grounds the solid crust need not have a thickness of even 20 miles; while, on the same grounds, the dimensions required for the underlying molten layer, in order to place it in concordant relation with the ascertained mobility of the crust during the later geological periods, are those of a mass sufficiently large for the play of movements such as would come within the compass of continental (not mountain) elevations and depressions; and for this object and for the purposes of vulcanicity, a molten layer having a thickness measured not by hundreds, but by tens of miles, would fulfil the necessary conditions.

Viscidity of the Magma. It is quite possible, as suggested by Scrope, that, owing to pressure, the fusion-point of lava at great depths is higher than at the surface; and that the lava may, and probably does, exist at depths in a viscid or plastic state, and only becomes fluid as it rises to the surface and the pressure is removed. This state of viscidity accords with the excessively slow rate of movement and steadiness of the great continental elevations and depressions—changes in close interdependence, and due possibly to the slow transference from one area to another of a partially resisting plastic medium within confined limits.

Further, it follows from the fact of upheaval that the igneous rock ejected is not only replaced, but that it is often replaced by a quantity larger than that which is lost by extravasation. This could only be effected by supplies from adjacent areas of similar matter; in other words, it indicates that there must be a common fluid or viscid substratum, yielding to depression in some areas, and to upheaval in others, the loss in the one case being counterbalanced by centralisation in the other.

A compression in one part should therefore be followed by expansion in another, and by a deformation of the crust over conterminous areas. These conditions are in effect exhibited in the great continental upheavals and depressions so rife in the times immediately preceding our own, and still in a measure of perceptible action in certain parts of the world, as, for example, in the slow uplifting of the northern portions of the Scandinavian and Greenland peninsulas and subsidence of their southern portions.

Origin of Mountain-chains. In the first volume of this work (Chapter xvii) I touched upon one branch of this subject, and pointed out the distinction between the slow broad continental movements and the more compressed and linear elevation of mountain-chains; but the main questions then before us in connection with mountains were their general characters, direction, and comparative age. We have now to consider the causes which may have led to their formation.

Lateral Pressure. The theory most generally accepted by geologists [1] is that the formation of mountain-chains has been due to the gradual cooling of the globe, or secular refrigeration, in consequence of which the outer shell, in order to adapt itself to the contracting nucleus, has been compressed, deformed, and fractured along certain lines of least resistance. The crests of the vast folds caused by the tangential thrust, or lateral pressure, arising from this contraction, became developed into mountain-ridges parallel to one another within certain distances, and varying in number from one or two to ten or more. In Vol. I, Fig. 3 of the Plate at p. 304 shows the succession of these folds in the structure of the Alps. The strata, however, are in general so much broken by faults, often of great magnitude, and exhibit such complicated inversions that the symmetrical arrangement shown in that section (in which the faults, however, are omitted) is not always to be readily recognised. The original features are also greatly disguised by the excessive weathering by frost, snow, ice, and rain which the mountain-ridges have undergone since their elevation, and by which much of their substance has been removed.

Other Causes. Some geologists, while admitting the action of lateral pressure, consider that the contraction caused by cooling is in itself insufficient to produce the inequalities as they now exist on the surface of the globe. The Rev. O. Fisher [2] at first suggested, as one additional cause, the extravasation of water-substance from beneath the crust, but ultimately came to the conclusion that neither this nor secular contraction appeared to him adequate to produce the amount of compression which exists. Captain Dutton [3] arrived independently at very much the same conclusion that lateral pressure is insufficient; he attributes great importance to massive depositions causing uplifts by their weight along the weaker lines where the thickness of the strata is less. The reasoning, in these cases, is intimately connected with the rate of increase of temperature with depth, and on the temperature at which the rocks solidify,—elements in

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[1] See Constant Prevost's 'Théorie des Soulèvements,' 'Bull. Soc. Géol. France,' vol. ix. p. 183; Elie de Beaumont's 'Système des Montagnes' and 'Géologie Stratigraphique;' De la Beche's 'Theoretical Geology;' Pratt's 'Figure of the Earth;' Fisher's 'Elevation of Mountains by Lateral Pressure,' 'Trans. Camb. Phil. Soc.,' vol. xi. p. 504; Mallet's 'Volcanic Energy,' 'Phil. Trans.' for 1872; Dana's 'Results of the Earth's Contraction,' 'Amer. Journ. Science and Arts' for June to September, 1873; E. Suess, 'Entstehung der Alpen;' De Lapparent, 'L'Origine des Inégalités de la Surface du Globe;' 'Revue des Questions scientifiques' for July 1879, and his several subsequent papers on the movements of the Earth's Crust, in 'Bull. Soc. Géol. de France,' 3^{me} sér., tome x. et seq.

[2] 'Physics of the Earth's Crust,' chaps. vii. and x.

[3] 'Geol. Mag.,' Decade II, vol. iii. pp. 322, 370.

themselves of much uncertainty; and in a question of such extreme complexity, it may also be doubtful whether other elements may not have been overlooked[1]. The subject is one of great difficulty, and the student will do well to consult on this and other points connected with the condition of the Earth's Crust, the variety of problems bearing on this subject discussed in the works mentioned in the notes in p. 545 and below.

Some writers have also contended that the weight of the great sedimentary masses, where they attain proportions of 10,000, 20,000, or even 30,000 feet, would cause a depression of the crust in the receiving basin, while it would tend to force up the land-area from which the materials had been derived, and where therefore the crust had been weakened. These causes may possibly have produced, especially in early geological times when the crust was less rigid, movements in those particular areas; but it seems to me more probable that these infillings were secondary results subordinate to the potent master-movements due to contraction[2].

Varied effects of Contraction. The contraction, as I understand it, is productive of two orders of movement—the one, continental,

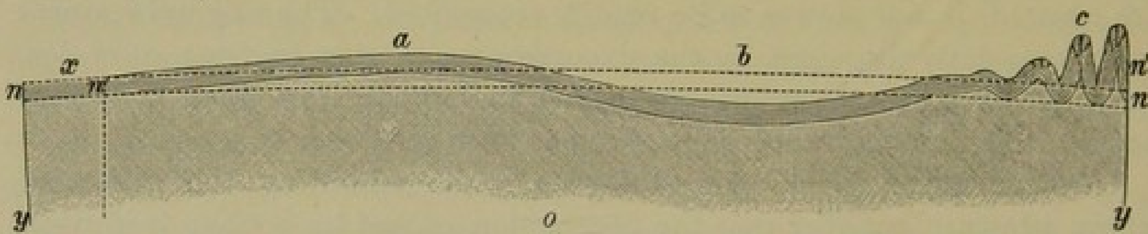

FIG. 255. Generalised Diagram, illustrating Mountain and Continental Elevation.
a. *Area of Continental Elevation.* b. *Area of Depression and Submergence.* c. *Area of Compression, Ridging, and Mountain Elevation.* (The two larger folds are too high, and should lean over slightly to the left.)

extending over large areas and of extreme slowness; the other, due to the yielding of the weaker lines in the crust, when the tension caused by the excessive strain (and of which the first order of movement is an index) overcomes the resistance, and fractures and doubles up the strata along those lines of lesser resistance. Mountain-ranges are in fact the concluding term of the stress which caused the deformation of the crust, and the movements which at those times took place must have been influenced by the greater energy of the strains then at work.

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[1] Since these pages were in type Mr. Mellard Reade's special work on 'The Origin of Mountain Ranges' has been published.

[2] Attention has been called by the American geologists to a minor and local form of elevation. It would appear that in some Volcanic districts of the West, trachytic lava, unable to find a vent at the surface, has forced itself laterally between the strata in lenticular masses, and has thereby tilted them into dome-shaped hills of not inconsiderable height and extent. To these injections, Mr. G. K. Gilbert has given the name of 'Laccolites.' They are cases somewhat analogous to the horizontally injected Whinsills of the north of England (see Vol. I. p. 399); but owing probably to its greater fluidity, the Basalt extended laterally for great distances, while the more viscid Trachyte expanded vertically to a height of from 4000 to 5000 feet, raising the strata with it, but without itself reaching the surface.

This may be illustrated by the foregoing diagram, in which *a* represents an area of continental elevation—*b*, of submarine depression, and *c* a line of yielding and of mountain-compression—the whole being due to the circumstance that the plate *n n* (which we may take to represent the solid Crust) has been subject to a lateral thrust in consequence of the contraction of the underlying molten or viscid mass *o* beneath it. The cause of this is not difficult to understand; for, as any section of the Earth's Crust, Fig. 255, prolonged in the direction of *y y* to a point in the centre of the Earth, represents a segment of the whole crust, each segment, in which the space between *y y* becomes gradually narrower, acts as a barrier and opposes a resistance to any changes of dimensions in the adjacent segments. Any one segment will therefore represent the conditions affecting the whole. Consequently, if the contraction due to secular refrigeration of the central mass *o* reduces the volume of the segment to such an extent that the plate or crust *n n* is reduced to narrower limits within *l l*, it will have to adapt itself to those more circumscribed limits. If this loss be represented by *x*, then *n n* becomes shortened to *n′ n′*, which must result in the deformation of the original plate *n n*, and to its eventual compression and fracture, along the lines of least resistance, when the limits of its elasticity are reached.

Ocean-Basins and Archæan Lands. It will be seen by the preceding remarks how intimately the great depressions of the Earth's Crust are connected with its elevations. The major of those depressions form the great Oceanic troughs or basins. Like the wide Archæan land-areas of Europe and America, parts of them have probably a high geological antiquity. The land-areas, plotted out at very early periods, and of which only portions are now visible—the larger portions having been covered up by later deposits—formed centres subject to irregular alternating movements of elevation and depression, so that at certain times one portion, and at others another portion, was under water. Consequently, round these centres the many deposits constituting the several great series of Formations have gradually grown up. I cannot, however, agree in the lengthened permanence, as a whole, of the Ocean-troughs. It is evident that these have undergone, at various geological periods, extensive modifications both in shape and direction—for example, during Cretaceous and Eocene times a great Ocean must have stretched from the southern latitudes of North America across to Southern Europe and Asia; while in early geological times the seas were less deep and had a greater breadth and extent. It must also be borne in mind that, with age and increased rigidity of the crust, the great depressions have become deeper, and so increased the area of the land and contracted that of the seas. It is therefore probable that it is only the deeper portions of the great Ocean-troughs that can claim the high antiquity which is now advocated for them by many eminent American and English geologists (see Vol. I. Chapter viii, and Map, p. 216, for contour-lines of Ocean-depths).

Effects of deep Cold Currents. Another cause which must have sensibly affected the stability of the Ocean-beds—in the later more than in the earlier geological periods—arises from a circumstance I have before had occasion to notice[1]. It is now well established by the observations made during various French and English scientific expeditions, that great sheets of cold water, at 32° to 35° Fahr., sweep over the Ocean-beds from the polar seas to the equator, where they rise to the surface, are there heated by the tropical sun, and thence return as surface-currents towards the poles; thus establishing a wonderful system of circulation whereby the cold of the polar seas is tempered, and the heat of the torrid zone mitigated; for the temperature of the surface-water of the great oceans, even in the latter zone, never rises above 80° to 84° Fahr.[2] Hence there is a difference of some 30° to 50° between the surface-temperature of the land in tropical regions, and that of the sea-bed in similar latitudes,—a difference which was probably still greater in Glacial times. Taking for those latitudes a mean surface-land-temperature of 75°, and a submarine temperature of 34°, and estimating the temperature of the Earth's Crust to increase with depth at the rate of 48 feet for each degree Fahr., the isothermal lines of equal value will there lie at a depth of about 2000 feet lower under the ocean than under the land. The thickness of the crust under the sea-bed should therefore be greater than under the land surface, and its stability greater—conditions affirmed by recent physical observations[3].

Effects of a General Refrigeration. If, as seems certain, the temperature of the polar seas, before the insetting of the Glacial Period, was higher than it is now, the temperature of the abyssal equatorial waters must also have been higher; whilst during the Glacial Period it was probably, as a whole, still lower than at present. The full effects of the deep cold stratum can therefore date only from comparative recent geological times. The same primary cause,—the cold of the Glacial Epoch, which, we have shown reason to suppose, embraced the whole Globe,—must, however, have produced a similar abnormal loss of heat both on the land and under the waters. Until that Epoch we may presume the refrigeration of the crust to have been comparatively regular and gradual, and nearly equal in given times; but with the very exceptional degree of cold to which the Earth was then for a lengthened period subjected, the effects could not be other than to cause a more rapid cooling than that

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[1] Oxford 'Inaugural Lecture,' January, 1875; Macmillan & Co.

[2] The Author in 'Phil. Trans.' for 1874. See also the 'Reports of the Challenger Expedition.'

[3] Pratt's 'Figure of the Earth,' p. 206; M. Faye 'Comptes Rendus' for June, 1886.

which obtained before, or which exists now. The consequence would be that during that time the contraction of the crust would be more rapid, and the disturbances resulting therefrom greater in a given time; or, if I may so express it, the work done by the contraction due to secular refrigeration, in any given number of years during the Glacial Period, would be equal to that done, say in twice or some greater number of years, had not that Period intervened.

Therefore, during a certain term of years succeeding to, and to be measured by the length of, the Glacial Period (whether that be 10,000 or 20,000 or any other number of years), the disturbances of the crust would be at a minimum and its stability at a maximum. This is the condition under which I conceive the Crust of the Earth is now placed, and which, as I have before suggested[1], ensures that state of repose and immobility which renders it fit and suitable for the habitation of civilised man.

I feel in making these last observations that they are somewhat speculative, but it is impossible to avoid the conviction that the extreme and exceptional conditions which immediately preceded our own times must have left their stamp and impress on the earth in some such way as I have described; while the considerations they involve may help to explain some of the anomalies relating to the physical questions touched upon in the preceding pages; and afford another reason why the present state of things is, in many respects, no fair exponent of the past.

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[1] 'Phil. Trans. Roy. Soc.' for 1864, p. 305.

CHAPTER XXXV.

THE PRIMITIVE STATE OF THE EARTH.

TERRESTRIAL HEAT. NEED OF A WORKING HYPOTHESIS. THE NEBULAR HYPOTHESIS. DENSITY OF THE EARTH AND PLANETS. ELEMENTS COMMON TO THE SOLAR ATMOSPHERE AND THE EARTH. SUCCESSIONAL ORDER OF THE ELEMENTS. METEORITES. AËROLITES: METALLIC AND STONY. ELEMENTARY SUBSTANCES FOUND IN AËROLITES; THEIR COMBINATION. DENSITY OF AËROLITES. ORIGIN OF AËROLITES; NOT VOLCANIC. FRAGMENTS OF ASTEROIDS; A POSSIBLE CLUE TO THE COMPOSITION OF THE DEEPER-SEATED TERRESTRIAL LAYERS. UNIFORMITY OF THE SOLAR SYSTEM.

State of Terrestrial Heat. With respect to the present surface heat, we have already shown, from considerations of physical geography, that there has been no apparent difference of climate due to solar heat in Europe since Roman times, or in Palestine since Hebrew times; and astronomical observations prove that the mean temperature of the globe, considered in its entire mass, and not on its surface alone, cannot have varied the fiftieth part of a degree during the last two thousand years. Herschel says[1]: 'The escape of heat from the interior, through the external shell of the Earth out into the air and free space, must be of most inconceivable slowness, so much so that no appreciable share in producing or maintaining the warmth of the *surface* can be attributed to it, and that the difference of climates and local temperatures is the result entirely of external influences.' At the same time, 'not only do the phenomena of volcanoes and hot springs indicate unmistakably the still further increase of heat beyond the reach of artificial excavation, but the fact itself, that the mean density of the globe is so small as 5½, must be held conclusive evidence of an excessive internal temperature.' He also remarks that, 'Whatever be the intensity of that heat, and whether the central portions of the globe be solid or fluid, there can be no doubt that the density of the materials of which it consists must, in proceeding downwards, follow an increasing progression.'

Geological observations are insufficient to prove with certainty the correctness of the latter inference, though, so far as they go, they are

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[1] 'Physical Geography,' 2nd edit., pp. 6–8.

conformable with it (see Vol. I. p. 396); while, as we have just seen, there are innumerable geological phenomena which prove not only an excessive temperature but also a molten condition of the interior,—a condition most apparent in the earlier stages of the Earth's history,—and for which some explanation has to be sought in its first origin.

Need of a Working Hypothesis. The period with which we have at first to deal is so remote and obscure, and the phenomena present so much variety and are often so complicated, that we feel the need of a working hypothesis, not necessarily for adoption if subsequent facts show cause for doubt, but as a guide for the classificatory advantages which the use of a working hypothesis presents.

The hypothesis which best answers to the geological requirements is that according to which the whole of the Solar System, at its origin, formed a nebulous mass, from which all the bodies of our planetary system have been evolved. Although Palæontological Geology commences with the time when the crust of the earth became solidified and life appeared on its surface, it is not possible to follow the course of the physical changes of the crust, which have been in incessant operation since that time, without some assumptions as to the anterior conditions of the Globe, for on those conditions its subsequent mutations are dependent. If the consequences of the astronomical hypothesis harmonise with the phenomena observed by the geologist, the latter may safely adopt that hypothesis for the purposes above-named, and follow up the consequences of its adoption.

For these reasons the geologist has to take up the history of the Earth at the point where it is left by the astronomer, and fill up the debateable ground,—the barrier beyond which the astronomer does not care to go, and which the geologist hesitates to approach. The former deals with the subject so long as it relates to cosmical questions; but when it passes into terrestrial questions, he hands it over to the physicist and geologist, whose object it should be to preserve unbroken the continuity of events. Though the subject is so closely connected with questions of cosmogony, it is also so closely related to others with which the geologist has subsequently to deal, that it forms an indispensable base for the geological superstructure.

The Nebular Hypothesis. It has been demonstrated that the figure of the Earth is not quite that of a perfect sphere, but approximately that of an oblate spheroid, such as would result from its rotation in a fluid state—the axes measuring respectively about 7926 and 7899 miles, or with a difference of 26½ miles between the equatorial and polar axes. This calculation makes the ellipticity of the Earth to be $\frac{1}{293}$; while according to the geodetic measurements recently completed, founded on the triangulation of the great Anglo-French, Russian, and Indian meridional arcs, it is $\frac{1}{297}$. This near coincidence between the ellipticity of the surface derived from theory with that which geodetic measurements give is very remarkable, and may be considered as almost conclusive proof of the correctness of the reasoning.

It has also been found, that all the other planets are spheroids, and not true spheres; the ellipticity varying as the velocity of rotation. It has been further determined that all the planets rotate in one direction, and with one doubtful exception, all their satellites also; and moreover, that all the planets revolve round the sun in one direction, namely from West to East. It has been concluded therefore that this uniformity of direction must have arisen from some one primary and common cause, by which the movements of the whole were determined.

So exceptional would such a uniformity otherwise be, that Laplace computed the probability in favour of all the motions of the planets both of rotation and revolution having been at once imparted by an original common cause, to be as four millions to one. The one common cause he conceived to be connected with an original nebulous condition of the whole Solar System, this nebulous matter filling the space occupied by the Planetary System, and moving like it round a centre; and that by the secular refrigeration and condensation of this nebulous matter, the Solar System was elaborated,—the primeval rotation of the nebula being still maintained in the rotation and revolution of the Sun and all the bodies of the Solar System in the same direction.

According to Laplace this immense vaporous mass was intensely hot, and had a slow rotation on its axis. As it slowly cooled, it contracted towards the centre; and, as it contracted, its velocity of rotation increased, so that a time arrived when at the outer boundary of the mass, the centrifugal force would counterbalance the attractive force of the central mass. The outer portions would then be left behind as a revolving ring; while, the next inner portions continuing to contract, the same process would be continuously repeated, and a series of rings formed. Some portions of these rings, being denser than others, ultimately attracted the other portions, and formed solid centres (the planets), surrounded by immense atmospheres of hot vapour. To this construction of the hypothesis it has been objected, that the rate of cooling would be such that the temperature of the sun would cool down more rapidly than calculation warrants, and that it suggests no mode by which the supply of heat is kept up.

Another form has been given to the nebular hypothesis, which, while it assigns a reason for the maintenance of the heat of the sun, still holds to the condition, so important in a geological point of view, that the planets were originally formed of vaporous matter, and that this, as it condensed, passed into a fluid state, due to the intense heat developed by that condensation.

This more recent construction of the hypothesis is based on the assumption that the heat of the sun is produced by the contraction of its mass, or by the conversion into heat of the forces attendant on the gravitation of the particles of matter into the central body. This requires no secondary or outside cause, and is in harmony with the modern doctrine of the conservation of energy. A slow loss of heat through untold ages involves a very small annual contraction of the Sun's diameter; but, small as it is, it would follow that the Sun's atmosphere must at former periods have extended far beyond its present limits; and, on a long retrospective view into past time, the vaporous mass may not only have successively passed the orbit of the Earth, but have extended to the outer boundaries of the Solar System itself. With the gradual loss of heat, the nebulous mass contracted; and, as it contracted, we are led, paradoxical as it may appear, by the known laws of the specific heat of gaseous matter, to conclude that it became hotter, and that, as the mass became denser, the heat would become so intense that, on their first consolidation, the earth and all the planets were molten fluid bodies. This hypothesis, which is in accordance with the astronomical conditions, is also the one which, in its connection with secular refrigeration, adapts itself best, there is little doubt, to the great problems in physical geology.

a b

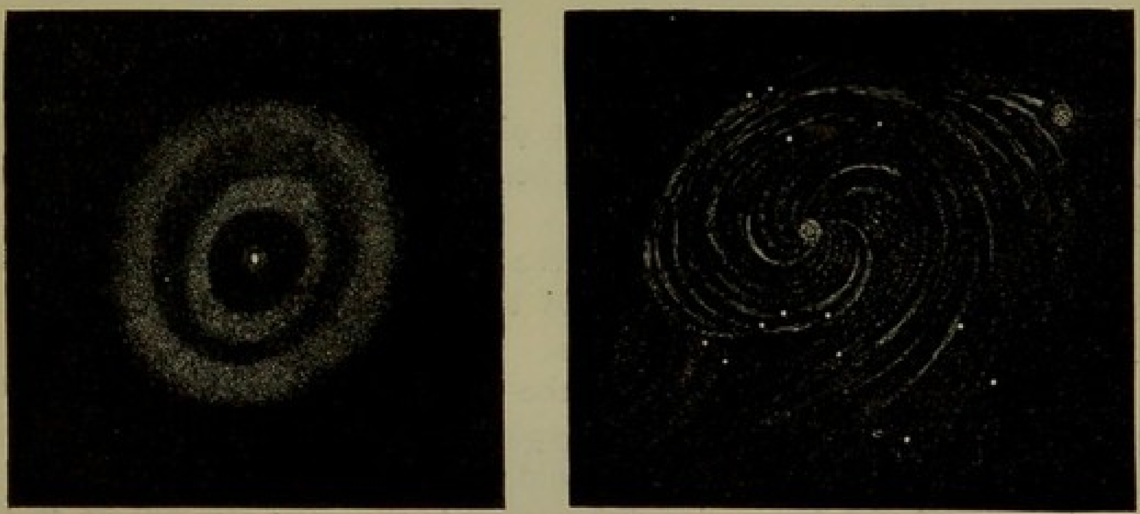

FIG. 256. *a. Planetary nebula in 'Hydra'* (after Lassell). *b. Spiral nebula in 'Canes Venatici* (after Lord Rosse).

The above figures of two remarkable nebulæ may serve to illustrate the condition of cooling vaporous matter in a manner analogous to that which we suppose to have existed in our own planetary system.

Density of the Earth and other Planets. Taking the density of water as 1, it has been found that the density of the Earth is rather more than 5½, which is about double that of our hardest and heaviest rocks,—that of granite averaging 2·65, and of basalt 2·95. The density of the lighter metals, for example iron, is 7·5, that of silver 10·5, and of mercury 13·5; whilst of the heaviest, that of gold is 19·5, and of platinum is 21·5, being the highest of all except that of osmium, which reaches 22·47.

Assuming the density of the Earth to increase with depth from the surface, it has been supposed that the constituent materials were arranged in zones of different densities; that the original outer crust consisted—1st, mainly of purely felspathic materials; 2nd, of materials richer in lime, magnesia, iron, etc.; 3rd, with iron in still larger proportions; while the centre consists possibly of metallic elements alone.

If we compare the densities of the planets with that of the Earth, we find that, as a rule, their densities decrease as they recede from the Sun; that of Mercury being one-fifth more than that of the Earth, or rather greater than that of antimony and less than that of zinc; whereas the density of Neptune, which is the most distant of the planets, is only one-fifth that of the Earth, being little more than the density of water[4], or about that of pitch. These densities are, according to Newcomb, as under:—

	Water=1.	*The Earth*=1.
Neptune	1.15	0.20
Uranus	1.28	0.23
Saturn	0.75	0.13
Jupiter	1.38	0.24
Mars	4.17	0.74
Earth	5.66	1.00
Venus	4.81	0.85
Mercury	6.85	1.21

In the same way, the satellites of the planets are lighter than the planets themselves: the density of the Moon being rather more than one-half that of the Earth.

All these points connected with the physical constitution of the Solar System are therefore such as would best agree with the theory of a common origin from a nebulous mass.

This was the position in which the question stood until about thirty years ago. Since then the nebular hypothesis has received from physicists corroboration of a most unexpected and marvellous character.

The wonderful discoveries with respect to the solar atmosphere, made by means of the spectroscope, have now presented us with an entirely new class of evidence, which taken in conjunction with the argument derived from figure and system, gives almost irresistible weight to the theory of a common origin of the sun and its planets: and, while it connects our earth with other planets, it indicates as a corollary what of necessity must have been its early condition and probable constitution. That being the case, we have a reasonable warrant for assuming, not only the original nebulous state of the Earth, but also (owing to the heat developed by the gravitation and consolidation of its mass) its subsequent molten condition,—the formation of an outer crust as it gradually cooled,—its secular refrigeration during long geological time,—and all the other consequences of contraction and shrinkage, which must inevitably have ensued from the continuous loss of heat, and from the diminution in volume of the cooling nucleus.

Elements common to the Solar Atmosphere and to the Earth. It has been before mentioned (Vol. I. p. 9), that the whole number of known elements composing the crust of the Earth amount only to sixty-four (now increased to sixty-six); and that of these it is calculated that Oxygen in combination forms by weight one-half, and Silicon a quarter; then follow Aluminium, Calcium, Magnesium, Potassium, Sodium, Iron, and Carbon. These nine together have been estimated to constitute $\frac{977}{1000}$ of the Earth's crust. The other $\frac{23}{1000}$ consist of the remaining fifty-seven non-metallic and metallic elements.

The researches of physicists[1] have now made known, that of these sixty-six terrestrial elements, twenty-one are present in the Solar Atmosphere; while the spectroscope gives no indication of any unknown elements. The elements thus discovered consist of—

1. Aluminium.	7. Cobalt.	12. Magnesium.	17. Sodium.
2. Barium.	8. Copper.	13. Manganese.	18. Strontium.
3. Cadmium.	9. Hydrogen.	14. Nickel.	19. Titanium.
4. Calcium.	10. Iron.	15. Oxygen.	20. Uranium.
5. Cerium.	11. Lead (?).	16. Potassium.	21. Zinc.
6. Chromium.			

In the above list we have:—

Two Permanent gases	*Hydrogen*	... *Oxygen.*	
Two Metals of the Alkalies	*Sodium*	... *Potassium.*	
All three Metals of the Alkaline Earths	*Calcium*	... *Strontium*	... *Barium.*
Three Metals of the Zinc class ...	*Magnesium*	... *Zinc*	... *Cadmium.*
All the Metals of the Iron class ...	*Manganese*	... *Cobalt*	... *Chromium.*
	Iron	... *Nickel*	... *Uranium.*
Two Metals of the Tin class	*Tin*	... *Titanium.*	
One Metal of the Lead class (probably)	*Lead.*		

While these phenomena afford such strong additional proofs of the common origin of all the bodies of our Solar System, Mr. Norman Lockyer has been led to form some views of great interest bearing on the probable structure of the crust and nucleus of the earth. Observations and theory have led him to the unexpected conclusion, that, in the case of an atmosphere of enormous height and consisting of gases and of metallic elements in a gaseous state, gravity overcomes diffusion, and the various vapours arrange themselves in layers; and that in the sun, where owing to the fierce solar temperature the elements exist in a state of vapour and of complete

[1] Kirchhoff, Ångström, Thalèn, Huggins, Norman Lockyer, and others.

dissociation, the several elements arrange themselves in the main in the following order:—

Coronal Atmosphere	Cooler Hydrogen.	
Chromosphere	Incandescent Hydrogen.	
	1. Magnesium.	2. Calcium.
Reversing layer	1. Sodium.	4. Iron.
	2. Chromium.	5. Nickel, etc.
	3. Manganese.	

Or, taking them in the order of their atomic or combining weights, they may be arranged in the following order:—

	New Atomic Weights.		New Atomic Weights.
Hydrogen	1.00	Chromium	52.54
Sodium	22.99	Manganese	54.8
Magnesium	23.94	Iron	55.9
Calcium	39.9	Nickel	58.6

The metalloids or non-metallic elements, as a group, are supposed to lie outside the metallic atmosphere, forming the reversing layer which surrounds the Photosphere.

Successional Order of the Elements. If now we turn to the Earth's crust, we find some reason to believe that the mass of igneous magma which underlies the sedimentary strata, and forms the outer coating of the central nucleus, may be divided into two great layers, holding a definite relation one to the other,—a lighter upper layer, consisting of the materials of granite, trachytes, and other rocks, rich in silica, moderate in alumina and alkalies, and poor in lime, iron, and magnesia; and of a lower mass of volcanic and basaltic matter of greater specific gravity, with silica in smaller proportions, alumina and the alkalies in the same, and iron, lime, and magnesia in much larger proportions, and with some other elements as occasional constituents; while the denser metals are in larger proportion in the more central body of the nucleus. This order follows necessarily from the original localisation of the earths and metals suggested by Mr. Lockyer, in accordance with which the oxygen, silicon, and other metalloids formed, as now in the Sun, an outer atmosphere, succeeded by an inner envelope, consisting in greater part of the alkaline earths and alkalies, then by a lower layer of iron and its associated group of metals, and finally by an inner nucleus containing the other and denser metals[1].

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[1] The hypothesis of dissociation finds support also in the constitution of the other planets. For the low density and gigantic and highly absorbent atmospheres of the outer planets accord with their being more metalloidal; and on the other hand, the high density and comparatively small and feebly absorbent atmospheres of the inner planets point to a more intimate relation with the inner layers of the original nebulous mass. The lunar system of Jupiter, and our own moon, further support the hypothesis, inasmuch as the density of the satellites is less than that of the primaries.

As before mentioned (Vol. I. p. 10), above nine-tenths of the Earth's crust consist of those elements which, on the assumption of the external position of the metalloids, would constitute the outer layers of the nebular mass. Thus oxygen and silicon alone constitute, on the average, $\frac{75}{100}$ of the mass of the outer layer of acidic rocks; while beneath it are the basic rocks, into the composition of which calcium, magnesium, and iron, combined with oxygen, enter in the proportion of, say, $\frac{35}{100}$; while the proportion of the silica is less by $\frac{25}{100}$: still deeper lie the denser and harder metals, which reach the surface through fissures traversing the outer layers.

The reader will not fail to remark, in the above observations, that silicon, which enters so largely into the constitution of all the rocks, does not appear amongst the substances of the Solar atmosphere. The lines of oxygen are so obscure that they have only been recently detected in the Sun; while those of silicon have as yet altogether escaped observation. Even, however, in rocks where these substances are present in large proportion, the spectroscope gives, as in the Sun, no signs of their presence. In a preliminary examination, kindly made for me some time ago by Lockyer, of two specimens of igneous rocks, the following were the results given by spectroscopic analysis :—

Constituent Substances of the two rock Specimens.	Lava.	Greenstone, Clee Hill.	Present in the Solar Atmosphere.
Oxygen ... ... }	not shown	not shown	{ *
Silicon ... ... }			{ not detected.
Magnesium	... ? ...	... ? ...	... *
Aluminium	... * ...	... * ...	... *
Calcium	... * ...	... * ...	... *
Sodium ... ... }	traces ...	... * ...	... *
Potassium ... }			
Manganese	... ? ...	... ? ...	... *
Iron	... * ...	... * ...	... *

Meteorites. Another argument in favour of the unity of the elements throughout the Solar System is furnished by the Meteorites (see Vol. I. p. 150), which so often fall from outside space. It is only with the denser or more solid masses that we are concerned. The more nebulous masses become so heated in coming in contact with our atmosphere that they are burnt and dissipated before reaching the Earth. But the more solid and resisting masses, the Aërolites, though fused externally, and often shattered into fragments, are constantly falling on the surface of the Earth, and prove to be not only telling witnesses of the original community of the elements, but also corroborate to some extent what has been inferred theoretically with respect to the order of succession of the elements in the Earth, for a singular analogy exists between many of these Aërolites and some of the deep-seated terrestrial rocks.

Aërolites may be divided into—firstly, the stony; and secondly, the metallic, though they pass into one another by insensible gradations. M. Daubrée divides them into four groups[1]:—

1. Those composed entirely of metallic iron (Holosiderites).
2. Those in which the iron forms a continuous mass, through which stony particles are disseminated (Syssiderites).
3. Those in which iron is present in the form of grains (Sporadosiderites).
4. Those which consist entirely of mineral matter without any *metallic* iron (Asiderites).

1. The first of these groups generally consists of pure malleable iron, mixed with small proportions of nickel and cobalt. The following analysis shows the commonly relative proportion of these substances in the metallic Aërolites:—

Iron	92.7
Nickel	5.6
Chromium, Cobalt, traces of Silicon ...	0.9
	99.2

Besides these, a sulphide of iron, a phosphide of iron and nickel, a sulphide of chromium and iron, and magnesium are occasionally present. Another remarkable circumstance connected with these metallic aërolites is that they present a crystalline structure; and, on subjecting a polished flat surface of the iron to the action of an acid, a portion of it is eaten away, while other parts are left in relief in lines parallel to two faces of a regular octahedron (Widmannstaetten's figures).

2. In the second group, the iron contains grains, sometimes of a silicate of magnesia and iron-protoxide, identical with the common mineral olivine (peridot), at other times of a mineral allied to augite. It is these stony groups, in which the mineral matter exists in combinations like those which occur on the Earth, that are of especial interest to the geologist. For example, an Aërolite which fell at Montréjeau (Haute Garonne), in 1858, was found by M. Damour to consist of—

Nickeliferous Iron	11.60
Magnetic Pyrites	3.74
Chrome-iron	1.83
Peridot (olivine)	44.80
Hornblende and albite	38.00
	99.97

Another interesting feature connected with this sub-group is that they are often found to be traversed by bright slickenside surfaces (like those in mineral veins, Vol. I. p. 254), ending abruptly at the outside glaze, so that it

[1] 'Géologie Experimentale,' p. 506, and the Chapters on the Constitution of Meteorites.

is evident that these surfaces were produced before the breaking-up of the original mass into the several fragments.

3. The third, which is by far the more common variety of Aërolites (in the proportion of 10 to 1), has generally a crystalline structure, and contains nickel-iron in malleable grains, iron-sulphide and -chromate, together with certain well-known silicates, such as, in one instance, felspar (anorthite) and pyroxene in large proportion, and small proportions of titanic and phosphoric acids. The remarkable Aërolite which fell at Juvinas (Ardêche) in 1821 was found to be composed of—

Pyroxene (Augite)	62.65
Felspar (Anorthite)	34.56
Phosphate of lime (Apatite)	0.60
Titanate of lime	0.25
Chrome-iron	1.35
Magnetite	1.17
Magnetic pyrites (Pyrrhetine)	0.25
	100.83

In this class of Aërolites the minerals are not only similar in chemical composition, but also in crystalline forms, to the same terrestrial species. The above specimen presents even, according to M. Damour, a marked resemblance to some of the lavas of Iceland[1].

In another Aërolite of this group olivine is the dominant constituent. It is identical in composition with some varieties of this mineral found on the earth (in either case grains of chrome-iron being sometimes present), as the following analyses will show:—

	Aërolite of Chassigny (Haute Marne). *Damour.*	Olivine of the Kaiserstuhl in Brisgau[2]. *Walchner.*	Olivine of Waterville, (U.S.A.[3]). *Dana.*
Silica	35·30	31·62	38·85
Alumina	......	2·31	......
Magnesia	31·76	32·40	30·62
Protoxide of Iron	26·70	29·71	28·07
" " Manganese ...	0·45	0·48	1·24
Oxide of Chromium ...	0·75	......	......
Potash	0·66	2·99	CaO—1·43
Chrome-iron and pyroxene	3·77	......	......
	99·39	99·51	100·21

4. The fourth group of Aërolites, in which there is no metallic iron, though it is present as an oxide or combined, is very rare. This group is

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[1] 'Bull. Soc. Géol. de France,' 3me sér., vol. xix. p. 513.

[2] Dufrènoy's 'Minéralogie,' vol. iv. p. 332.

[3] 'Amer. Journ. Science,' vol. iii. p. 48.

characterised by the presence of carbonaceous matter, or some form of carbon, in combination with hydrogen and oxygen, and also by the presence of combined water, together with soluble and even deliquescent salts. Some of these Aërolites likewise contain a double carbonate of iron and magnesia, and some magnesian silicates, with the oxides of nickel, cobalt, and chromium. Magnetite and magnetic pyrites, in innumerable microscopic crystals, are occasionally present, as well as chrome-iron. The presence of combinations of carbon, such as might result from the decomposition of vegetable matter, is a very curious and interesting fact. Like the ordinary stony Aërolites, those of this class have received a glaze in passing through the Earth's atmosphere which protected their easily alterable substance from further change. These Aërolites are generally extremely friable, and are readily reduced to fine powder.

Elementary Substances found in Aërolites. These, as will have been seen, are in very near agreement with the elements found in the Sun by spectroscopic analysis, but they contain, in addition, a gas and a metalloid, of great importance from their abundance in the crust of the Earth, and of which the spectroscope gives scant evidence—namely, Oxygen and Silicon. The total number of the elements discovered up to the present day in Aërolites is as under:—

1. Oxygen.	8. Chlorine.	15. Arsenic.
2. Nitrogen.	9. Potassium.	16. Iron.
3. Hydrogen.	10. Sodium.	17. Tin.
4. Carbon.	11. Calcium.	18. Manganese.
5. Sulphur.	12. Magnesium.	19. Cobalt.
6. Silicon.	13. Aluminium.	20. Nickel.
7. Phosphorus.	14. Copper.	21. Titanium.

Besides these, the spectroscope shows the presence in the Sun of *barium*, *strontium*, *cadmium*, *cerium*, *lead*, *zinc*, and *uranium*, thus bringing up the number of the known elements in non-terrestrial bodies to 28 out of the total of 66 found in the Earth.

Further, we have seen that these elements commonly occur in Aërolites in the same combinations as on the Earth, forming various minerals common in terrestrial rocks, such as *olivine*, *augite*, *enstatite*, *anorthite*, *chromate of iron*, *manganite*, *oligiste*, and *graphite*: and not only are they alike in chemical composition, but they are so likewise in crystalline forms, and even in their modifications.

On the other hand, the elements are sometimes combined in Aërolites in a manner unknown on the Earth: thus there is a double phosphuret of iron and nickel, to which the name of *Schreibersite* has been given; a sesquisulphuret of chromium and iron called *Daubreelite*; a sulphuret of calcium termed *Oldhamite*, and a proto-chloride of iron—*Laurencite*.

Amongst the substances most abundant in Aërolites are oxygen, silicon, iron, and magnesium—substances which, as before mentioned, enter so largely into the composition of the rocks forming the crust of the globe. Of the presence of oxygen in a combined state there can be no doubt; and it is singular that the iron of the metallic Meteorites appears as though it had passed in a heated condition through an atmosphere of hydrogen; for Graham has shown[1] that some of these Aërolites contain as much as 2½ times their volume of occluded hydrogen, and this long after their fall.

Density. Another point of interest is that relating to the density of the Aërolites, in connection with that of the Earth and other planets. For example, taking the mean of the densities of the several classes of Aërolites given by M. Daubrée[2], and comparing them with a series of the acidic and basic igneous rocks, we have the following result:—

Aërolites.	Spec. Grav.	Rocks.	Spec. Grav.
Stony—no metallic iron ...	2.7	Rhyolite and Petrosilex ...	2.6
Iron in small quantities	3·1	Trachyte and Dolerite	2.7 to 2.9
,, larger proportion ...	3·5	Basalt, Gabbro, and Lherzolite	3·0 to 3.5
,, considerable	6.8		
,, solid	7·5		

The average density of the first three classes of Aërolites taken together is 3·1, while that of the series of igneous rocks, which we may suppose to represent the outer portion of the Earth's molten crust, is a little under 3·0. Or taking the average of all the above as representing the several parts of the original body, we get a mean density[3] of 4·7, that of the Earth being 5·6, of the Moon 3·5, and that of Mars 4·17. The terrestrial eruptions, even from the greatest depths, would appear only just to touch on the supposed more metallic substrata.

Origin of Aërolites. By some astronomers an extra-terrestrial origin has been ascribed to Aërolites; by others they are supposed to have had a volcanic origin on the Earth or its satellite. It has been suggested that at an early geological period the volcanic eruptions on the Earth were more violent than at present, so that the initial velocity of the ejected fragments may have been such as to carry them beyond the sphere of attraction of the Earth, in which case they would not return, but continue to move in orbits of their own; or that the same conditions may have obtained in the Moon during the period of her great volcanic activity. Another hypothesis is that these Meteorites are connected with the passage of comets, of which they formed portions of the tail, that have passed near the Earth. A third is that the Aërolites are fragments of Asteroids moving

[1] 'Chemical and Physical Researches,' p. 281.
[2] *Op. cit.*, pp. 506, 545.
[3] This, of course, is a very rough approximation, as it takes no account of the relative proportion of the several groups.

externally to the orbit of the Earth, and which by collision were shattered to fragments, and that these fragments, moving in a new orbit, occasionally come within the range of the Earth's attraction and fall on its surface.

Not Volcanic. Examined in the light of terrestrial phenomena, the last of these speculations seems the most probable. Besides the astronomical and physical difficulties connected with the hypothesis of ejection, whether from volcanoes on our own globe and its satellite, or from any of the planets, but upon which we cannot here enter further[1], there is no geological evidence to show that explosive eruptions were formerly of greater energy than at present, but the contrary. Volcanic action was no doubt more frequent and active; but it is probable that the paroxysmal eruptions have attained their maximum intensity on the Earth in the more recent geological times (see Vol. I. p. 448).

Again, the stony Aërolites, although glazed by heat exteriorly, show interiorly nothing in the nature of scoriæ or slags; but, on the contrary, they show crystalline structure and an unoxidised state more compatible with slow cooling at great depths. But the most important point in favour of their previous consolidation and fragmentary nature is the fact, before mentioned, that some of the stony Aërolites are traversed by striated polished fractured surfaces, similar in appearance to the ordinary slickensides in many deep-seated rocks and in mineral veins. Not that I would suggest these to be portions of mineral veins, but that they are fragments of a body of which the external crust was subjected, like the crust of the Earth, to disturbances due to the secular refrigeration of a heated nucleus; and that we have in these evidence of the consolidation of the original body before its fracture and disruption. Such a condition could not possibly obtain were the Aërolite either a body condensed directly from small portions of vaporous nebulæ, or were it ejected as some of the fused erupted matter of volcanoes.

Fragments of Asteroids. On the other hand, the several classes of stony Aërolites exhibit a gradation of mineral characters and of density to a certain extent analogous to those conditions which we have reason to suppose obtain in the solid parts of the crust of the Earth, and possibly other planets. We have, at the same time, in the extreme metallic condition of a section of the Aërolites, a possible clue to the conditions which may obtain in the more deeply seated and inaccessible portions of the Earth's crust. The fact also that the polished surfaces of the iron Aërolites, when acted on by an acid, show in relief distinct lines of crystallisation, as though the mass had been slowly cooled, is very suggestive of their having been parts of a large slow-cooling body.

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[1] See Newcomb's 'Popular Astronomy,' part iii. chap. v; Ball's 'Story of the Heavens,' chap. xxiii; and Daubrée's *Op. cit.*, part ii. chapters i, ii, iii.

It has been urged in favour of the terrestrial origin of Aërolites that all their elements are such as we find in the Earth; but, since it has been shown that the same elements exist in the Sun, and are probably common to the whole Solar System, this argument loses its weight. Further, although the elements are the same, they have entered into some combinations which, as we have before observed, are not known to exist in the Earth, showing that, although many of the conditions may have been similar, there were others which have produced special results of a peculiar and distinctive character.

Such are some of the chief facts connected with the constitution of the Earth, and of its probable origin as part of the Solar System,—an origin in harmony with all its subsequent history, and with the unceasing vicissitudes and change which the physical phenomena exhibit in the successive stages and phases of the long geological series of rocks forming the Crust of the Earth.

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GEOLOGY

CHEMICAL, PHYSICAL, AND STRATIGRAPHICAL

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