CHAMBERS'S
ELEMENTARY SCIENCE MANUALS.

HISTORICAL GEOLOGY

BY

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'THE GREAT ICE AGE.'

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PREFACE.

THE vital importance of diffusing some knowledge of the leading principles of Science among all classes of society, is becoming daily more widely and deeply felt; and to meet and promote this important movement, W. & R. CHAMBERS have resolved, on issuing the present Series of ELEMENTARY SCIENCE MANUALS. The Editors believe that they enjoy special facilities for the successful execution of such an undertaking, owing to their long experience—now extending over a period of forty years—in the work of popular education, as well as to their having the co-operation of writers specially qualified to treat the several subjects. In particular, they are happy in having the editorial assistance of ANDREW FINDLATER, LL.D., to whose labours they were so much indebted in the work of editing and preparing *Chambers's Encyclopædia.*

The Manuals of this series are intended to serve two somewhat different purposes:

1. They are designed, in the first place, for SELF-INSTRUCTION, and will present, in a form suitable for private study, the main subjects entering into an enlightened education; so that young persons in earnest about self-culture may be able to master them for themselves.

2. The other purpose of the Manuals is, to serve as TEXT-BOOKS IN SCHOOLS. The mode of treatment naturally adopted in what is to be studied without a teacher, so far from being a drawback in a school-manual, will, it is believed, be a positive advantage. Instead of a number of abrupt statements being presented, to be taken on

trust and learned, as has been the usual method in school-teaching; the subject is made, as far as possible, to unfold itself gradually, as if the pupil were discovering the principles himself, the chief function of the book being, to bring the materials before him, and to guide him by the shortest road to the discovery. This is now acknowledged to be the only profitable method of acquiring knowledge, whether as regards self-instruction or learning at school.

For simplification in teaching, the subject has been divided into sub-sections or articles, which are numbered continuously; and a series of Questions, in corresponding divisions, has been appended. These questions, while they will enable the private student to test for himself how far he has mastered the several parts of the subject as he proceeds, will serve the teacher of a class as specimens of the more detailed and varied examination to which he should subject his pupils.

NOTE BY THE AUTHOR.

This Manual of HISTORICAL GEOLOGY, although complete in itself, is yet intended as a supplement to the treatise on GEOLOGY of the same series, in which the methods of geological inquiry and reasoning are specially described, and the beginner is therefore strongly advised to master that treatise first. In attempting, within the narrow limits at his disposal, to give a representation of Historical Geology, the author has directed attention chiefly to the evidence from which former physical, geographical, and climatic conditions have been deduced, and has done what he could to present a lively picture not only of the state of the British area, but also of the various faunas and floras that have appeared within it, during the successive periods of the past. Of course, such a presentment must necessarily be incomplete, but it is hoped that, while not uninteresting in itself, it will afford the student a fair idea of the scope of geological inquiry, and aid him in further directing his studies.

EDINBURGH,
June 1876.

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HISTORICAL GEOLOGY.

INTRODUCTORY.

1. *Geological Structure.*—When the student has attained a sufficient knowledge of the principles of Geology and Palæontology, his next step is to apply that knowledge towards working out what is termed *geological structure.* He must attempt to elucidate the past history of some given district by ascertaining, first, the order of succession of the strata. To do so satisfactorily, he selects a good map, upon which he traces the boundaries of the various rock-masses, and indicates the direction in which these *dip* or are inclined. He marks, also, the lines of dislocation, and endeavours to make sure as to which is the *high* and which the *low* side of a fault. In the next place, he must carefully search the beds for fossils, and from these he draws his conclusions as to whether the strata have had a marine or fresh-water origin—whether they are deep or shallow-water accumulations, &c. When he has exhausted all the physical and palæontological evidence, he should be able to form some opinion as to the geographical and climatic conditions under which the strata were deposited; he should be able to point out the relative position of land and sea as it varied during successive periods—he should tell us something about the plants and animals that clothed and peopled the dry land and tenanted the waters, and the kind of climate under which they flourished. In short, he should restore, as far as he can, the old physical geography of the district he elects to investigate. It is only by such investigations

carried on in all parts of the world, that we are enabled to build up the geological history of our globe. For it must not be supposed that one country, much less any more limited area, contains in itself a complete epitome of all geological history. On the contrary, it will always be found that the rocky strata of a country, however extensive, contain but a fragmentary series of records, whole formations being often entirely wanting. Sometimes, indeed, a wide continental region appears to be built up of only one or two series of strata; while, on the other hand, a large successive series, shewing comparatively few blanks, is occasionally developed within a narrow circumscribed tract—as, for example, in the British area, which perhaps contains a more complete succession of formations than any other country in the world.

2. *Imperfections in the Record.*—The imperfections of the record in one place are more or less satisfactorily supplied by the rocks of some other region, and so the evidence is pieced together, and a somewhat connected history is produced. Even after such dove-tailing, however, it would be idle to suppose that we thus obtain a perfect record of the physical changes which have supervened during the past, or that the succession of life upon the globe is adequately represented by the numerous fossils which have been disinterred from the rocks. Many blanks in the record occur, arising partly from the fact that very wide areas of our globe have either not been examined, or are still but imperfectly known, and partly from the mode in which the strata themselves have been amassed; for every stratum of rock implies the destruction of some pre-existing bed or beds of similar materials. The younger deposits have been formed out of the waste of older strata, just as these have been derived from the demolition of rocks that preceded them. For the same and other reasons, it would be unreasonable to expect to find a series of fossils completely representative of the past life of the globe. Many fossils, which must at one time have existed, have been demolished along with the strata in which they lay entombed. And again, we cannot suppose that the life—animal and vege-

table—of any one period of the past was ever more fully represented by fossils, than the existing tribes of plants and animals will be by the few remains which are now being washed down into lakes and the sea from the land, or which become buried where they live and die on the floor of the ocean. Were the bed of the present seas to be upheaved, no doubt we should find heaps of shells, and fish-remains and other organic débris imprisoned in sediments of gravel, sand, mud, and silt. But many of these would be much worn and very imperfect; and however abundant the remains might be, they would yet be far from yielding a complete representation of existing terrestrial and marine life-forms. Moreover, if we bear in mind that such an elevated sea-bed would be subjected, first to the grinding action of sea-currents and waves as it rose out of the deep, and thereafter would undergo continuous degradation under the action of rain, frost, and running water, we must be convinced, that after the lapse of long ages, a very large proportion of the upraised marine deposits, with their fossil contents, would be demolished, carried down to lower levels, and swept out to sea.

3. *Orderly Succession of Geological Changes.*—Such considerations lead us to expect, what is literally true, that the geological record is very imperfect. And yet, notwithstanding this imperfection, it nevertheless affords indubitable evidence of a gradual progress in life, from lowly types up to more highly differentiated structures. It shews us that, although many physical changes may have been due to the paroxysmal action of the subterranean forces, yet that, upon the whole, the present has been slowly developed, as it were, out of the past. There has been no violent ending of life over the whole globe, and subsequent sudden introduction of entirely new forms; no abrupt demolition of continents; no precipitate redistribution of all the lands and waters simultaneously; no such violent world-wide cataclysms as were dreamt of in the early infancy of geological science. The oldest sedimentary deposits of which any record has come down to us, speak to us of prolonged and quiet periods, during which deposits—'the dust of continents

to be'—slowly accumulated upon the sea-bottom. Everywhere, indeed, the stratified or fossiliferous strata repeat the same tale. Now and again, it is true, we have evidence of subterranean disturbance, by which the crust of the earth was cracked, and the strata displaced; of volcanic action, when showers of stones and sheets of melted rock were erupted. But such phenomena, as every one knows, are taking place in our own day, and there is no reason to believe that subterranean and volcanic energy were either more widely spread or more intense in early geological times than they are now. The history of the globe, so far as the geologist can trace it back, is a history of slow and orderly development. All the great changes have been brought about by those agencies which are even now at work modifying the physical geography of our earth. No doubt we may reasonably conjecture that there was a time when certain forces of nature acted with more intensity than now. We can conceive that while the crust of the globe was yet thin as compared with its present thickness—before the earth had radiated so much of its heat into space—subterranean and volcanic action and the atmospheric agents were more energetic everywhere than at present. But of such a time we have no recognisable geological records. The oldest fossiliferous strata afford no grounds for believing that the condition of the earth's surface in the earliest geological ages differed in any marked degree from that which obtains now. Vast changes in the relative position of land and sea there have been; myriads of species of plants and animals have successively appeared, and then vanished for ever; the same climatic conditions have not always persisted in the same latitude, but ever and anon warm conditions of temperature have given place to cold, and *vice versâ;* but as regards the interval of time embraced by the geological records, we certainly cannot, as geologists, assert that the agents of change have now become less active or less intense than they were in earlier ages. There have been periods in the physical history of our earth when, no doubt, certain agents of change have acted with energy more extreme than now. But such periods appear to have been recurrent, and are with most reason believed to have been induced in the first place by changes in the eccentricity of the earth's orbit (see section 124). They have appeared at irregular intervals in the past, and they will reappear in the future. They do not therefore afford any support to the idea that the agents of physical change have been growing less energetic in the lapse of the ages.

4. When the organic remains of all the fossiliferous strata have been compared, it becomes evident that however many blanks in the record may occur, however fragmentary the life-history may be, yet the fauna and flora of our globe have been many times completely changed, and this in a very gradual and orderly manner—plants and animals slowly dying out, and being as gradually replaced by new species, which in like manner became extinct, and were succeeded by others. Gradual extinction of old, and evolution of new faunas and floras have thus been the rule; and the old notion of sudden and violent destruction of all life, followed by the immediate introduction of complete suites of new species, has been abandoned. These general results of Palæontology are in complete harmony with the conclusion arrived at by physical geology, and justify us in believing that the present condition of things is only the latest phase in a long series of changes; that the continents and islands, the rivers and lakes and seas, have ever been slowly changing, as they are slowly changing now; that the myriad tribes of plants and animals that clothe and people the globe are not separated by a strong line of demarcation from the species that immediately preceded them, but bear to these so strong a resemblance that many naturalists believe this to point to actual relationship. They hold that the living fauna and flora have been slowly developed out of those that went before them; that species, therefore, are not permanent and unalterable, but inconstant and variable; being modified by all the manifold influences which are included under the term, 'struggle for existence.' And this, they maintain, is the true explanation of the fact that the living fauna and flora of the globe diverge more widely

from extinct creations the further back we go in time. Thus, in the younger geological strata we expect to find the fossils more nearly allied to living plants and animals than is the case with the organic remains of the older strata. These remarkable results, which can only be barely stated here, will be better appreciated when the student has gained some knowledge of the fossils that characterise the main groups (formations) of strata, which we shall treat of according to their succession in time.

5. *Formations.*—The term 'formation' is used very laxly by geologists. Sometimes it signifies a group of strata of inconsiderable or merely local importance, and occasionally the word is applied to a single stratum. Those writers, however, who are more careful in matters of terminology, restrict the term 'formation' to those great groups of strata which are characterised by the presence of fossils having a *facies* so peculiar to themselves, that it not only serves to mark off the strata from overlying and underlying deposits, but to distinguish them wherever they occur throughout the globe. Thus, strata belonging to what is called the 'Silurian formation,' are characterised by the presence of fossils which preserve the same general *facies* or appearance in Britain and the European continent, in Greenland and in the United States, even although the species may not be the same throughout. The Silurian strata of America, for example, contain many fossils not met with in the Silurian rocks of England; while, conversely, not a few English Silurian fossils do not extend to the American region. This is what might have been expected. At the present time species are limited in their range; some cosmopolitan ones there are, but for the most part species of plants and animals alike are restricted to certain provinces. It was the same in old times; and hence we must not feel surprised that the fossils in widely separated contemporaneous strata should not contain quite the same assemblages of species. The limits of 'provinces' are no doubt often determined by climatic conditions; and, therefore, we can conceive how, under a highly equable temperature, and all which that includes, certain species might gradually

spread themselves over vast areas. And such has happened again and again in the past; so that in some formations we find numerous cosmopolitan forms. In Carboniferous times, for example, many species of plants seem to have ranged over the whole world. Nevertheless, we descry, even in the great coal-bearing formation (which was accumulated at a time when a genial and equable climate prevailed up to polar regions), abundant evidence of the geographical limitation of species. But, although species were thus restricted in their range in the past, just as they are in the present, yet a certain general facies characterised the fauna and flora of each great period. Again, each period was generally distinguished by the great development of certain orders or genera. Thus, the Silurian strata are everywhere marked by the presence of the extinct order of Trilobites, which are represented by very numerous genera and species; and another equally characteristic Silurian type is the Graptolite. By a 'formation,' then, it will be understood that we mean all the deposits, whether fresh-water, or marine, or terrestrial, which accumulated over the surface of our globe in lakes, in seas, and upon the land, at a time when the world was characterised by the presence of some particular and peculiar fauna and flora.

6. *Old Faunas and Floras gradually replaced by new.*—But if there has been no sudden and complete redistribution of land and sea in the past ages, nor any violent termination of all life and instantaneous introduction of new faunas and floras, then we need not expect to find any strongly marked line of separation between two formations. What we do find amongst conformable strata is a commingling of the faunas and floras at and near where one formation graduates into another. Some fossils appear in the lower formation in few numbers, getting more plentiful towards the top, until they become quite abundant in the upper formation, in which, however, they may eventually diminish as we trace them upwards, until at last they seem to die out altogether. Occasionally we meet with fossils which occur in many formations, having lived through the lifetimes of several successive faunas and floras. This is the case with many of

the lower forms of life. These being always the most numerous, they are better able to withstand exterminating influences. Thus it is believed that certain species of foraminifera found in some of the older strata of the globe are identical with species now living in our own seas. The lower the form, the greater the chance of its passing on from one formation up into another; and conversely, the more highly organised the form, the more likely is its vertical range to be restricted. Species of molluscs, for example, have a greater vertical range than species of fish, and the lower orders of molluscs range higher than those farther up in the scale of being. The living genus *Lingula* (Brachiopoda) has survived from Silurian times.

7. *Different Strata with same Fossils not necessarily quite synchronous.*—Remembering the conditions under which a formation has been amassed, we shall be prepared to find that separate areas of strata which contain as nearly as may be the same groups or types of species, are not necessarily strictly synchronous. We can conceive of species gradually dying out, and being replaced by new forms over a wide area of sea-bottom; and yet finding favourable conditions, and so lingering on, in other parts of the same ocean-bed, while a different set of organisms have usurped their habitats elsewhere. Or again, physical changes may compel species to migrate from one part of the sea-bottom to another; and as such changes will, as a rule, take place very gradually, and the resulting migration may likewise require a long time for its accomplishment, it follows that the deposits containing the remains of such species cannot be actually contemporaneous. If, for example, we suppose certain changes to take place in the area of the Arctic Ocean, which compel the species now living there to migrate slowly southwards to the latitude of Britain, it is evident that the shells, &c. lying in the silt of the far north, will be of older date than those which are inclosed in the sediment of their new habitat, even although the assemblage of species is precisely the same in both regions. So that, in short, the appearance of the same set of fossils in widely separated regions may, and no doubt often does, point rather to the same kind of

conditions having obtained, than to the actual synchronism of the deposits in which the fossils occur. Hence many deposits which are spoken of as 'contemporaneous,' may in reality belong to widely separated dates. It has been proposed to substitute the term *homotaxis* ('similarity of order') for *contemporaneous*, to widely separated deposits which contain the same assemblages of fossils. By this term we would not imply that the strata were formed contemporaneously, but would merely indicate that 'the order of organic succession was the same at both places.'

8. *Conformability and Unconformability.*—When one formation rests conformably upon another, we look for, as just remarked, an intermingling of old and new forms at the line of junction. For conformability merely means the continuance of the same or nearly similar geographical conditions; the one formation merges gradually and imperceptibly into the other; and in a true conformability there is really no division-line, such division being drawn often arbitrarily, and merely for convenience of classification and arrangement. In the case of unconformability, however, we observe that there is no intermingling of fossils in the two formations at the line of junction, but the fossils of the one are sharply marked off from those of the other. This clearly indicates a lapse of time—there is a gap in the record—the strata in which the intermediate fossils may have once existed have vanished. The physical evidence points in the same direction—for whereas the regular succession of conformable strata indicates the long continuance of similar geographical conditions, unconformability, on the other hand, proves a complete change of such conditions.

9. *Breaks in Succession.*—When, during the deposition of strata, physical conditions have been modified or changed, we expect of course to meet with a corresponding change in the fossils. Thus, when the sea gives place to estuarine or fresh-water conditions, marine organisms are supplanted by creatures of a fresh-water habitat. We often find, however, certain great changes in the fossils of a series of strata which cannot be so accounted for. Occasionally the fossils in the lower parts of such a series are strongly marked off

from those in the upper beds. All of them may be marine, but we observe a more or less complete change in the *facies* of the fossils—those in the lower beds differ, it may be, both specifically and generically, from the fossils in the upper beds. Now, it may be taken as proved that, whenever we find the fossils so widely divergent, a 'break in the succession' occurs, and this even when the strata appear to be quite conformable. We must infer the lapse of some long period of time to account for the dying out of the fauna or flora represented by the fossils of the lower strata, and for the coming in of the widely different species with whose remains the upper beds are charged. In such cases it usually happens that the appearance of conformability is deceptive, and when the strata are traced out over a wide area, the overlying beds are often found to steal gently over the ends or outcrops of the strata lying underneath. Indeed, wherever the fossils give proof of a break in the succession, the geologist must be on the outlook to detect such unconformability.

10. *Climatic Condition deduced from Fossils.*—From fossils also we frequently obtain more or less trustworthy evidence regarding the climatic conditions of the globe in past ages, as we shall point out more particularly in the sequel. When the fossils belong to living genera and species, conclusions as to climate are not only quite legitimate, but indeed force themselves upon us. But when we come to deal with the organic remains in strata belonging to the oldest members of the fossiliferous deposits, we cannot always be so sure as to the nature of the climate which these remains indicate. For frequently the old extinct species depart so very widely in character from present forms, that we are left to conjecture, and can only reason in a vague way from analogy. Thus, if we found a number of extinct reef-building corals in rocks within the Arctic Circle, we should be inclined to infer that the northern seas were warmer at the time these fossils existed as living creatures than the same seas are now. And this inference would be based upon the analogy of the present—for reef-building corals do not flourish in water whose temperature is under 60° F. Our inference would

be considerably strengthened, moreover, if in addition to corals we discovered in the same rocks a number of large chambered shells, and remains of ferns and cycads which, from their excellent state of preservation, had apparently not travelled any great distance. We could hardly believe that such forms of life, which are now characteristic of genial climates, should in former times have found fit conditions of life in a region where land and sea alike were covered to a large extent with ice.

11. *Conditions of Deposition deduced from Fossils.*—In much the same way we may reason from analogy as to the depth of the sea in which the fossiliferous strata have been accumulated. Every one knows that the fauna and flora of the sea are influenced by its depth—there are littoral and deep-sea species. With deposits in which the great majority of the fossils belong to living species, it is not so difficult to ascertain the depth at which the sediment has been accumulated; but, when we come to the older strata, in which all the fossils belong to extinct species, and most of them even to extinct genera, it is evident that we can never be so positive as to the depth of the sea in which they flourished. We must just reason from analogy, and be influenced in our conclusion by the general aspect of the fossils, and the nature of the deposits in which they occur.

12. *Preservation of Fossils.*—The peculiar chemical process which has affected nearly all fossils, and which has been in many cases the means of their preservation, has also frequently succeeded in removing all trace of organic remains from certain rocks. Water containing mineral matter in solution, when percolating through a sediment charged with organic remains, often removes the animal or vegetable structures atom by atom, replacing these, as it does so, with an equal amount of inorganic matter, such as silica, carbonate of lime, iron pyrites, and the like. When this mineral substitution is complete, the resulting petrifactions have preserved the character of the minutest tissues; so that a section of silicified wood, for example, yields as much information under the microscope as a similar section of the original tree could have done. But the petrifying

process is not often so complete as this; frequently, indeed, it is merely a cast of the harder parts which has been preserved; and it is only rarely that any portions of the internal softer parts of molluscs and crustaceans, for example, have been petrified. By far the great majority of fossils consist of skeletons, shelly coverings, teeth, scales, bark of trees, and tough ligneous tissues, &c. Yet, delicate insects, and tender and fragile plants, are sometimes detected. But the water that percolates through rocks, although it has thus often been the means of preserving fossils, yet has in many cases partly, or entirely, obliterated them. Shells, &c. have been dissolved out, little cavities being left to indicate their former presence. If the cavities remain, they may tell us so much; but, should the rock be only partially consolidated, then it is not difficult to conceive that the cavities might disappear by collapsing during the slow process of induration, or become invisible by being filled up with material not differing from that in which they are imbedded.*

13. *Geological History.*—From the various considerations touched upon in the foregoing paragraphs, it becomes evident that the past and the present are intimately linked together. The outline of land and water has assumed its present appearance only gradually, and after an infinite series of changes; the configuration of the land, the mountains and valleys, the rivers and lakes of the globe, have been produced by the prolonged and orderly action of those very same physical agents which are at present modifying the earth's crust, and which will change the face of all things in the future as they have again and again done in the past. In the same way the animals and plants that now tenant the globe blend with the creations which have preceded them. Ever since life was introduced, it has been acted upon by the forces which surround it. Old forms have successively disappeared as conditions became unfavourable, and new types better fitted for the struggle of existence have taken their place. Thus, in the

* When this happens, the filled-up cavities often appear on weathered faces of the rock.

process of time, the whole animal and vegetable worlds have been gradually but completely changed again and again, just as they will be in the future, should time endure. Now, if life has been persistent from its introduction, and if, during that time, lands and seas have always existed, then there must be a continuity in geological history, and any subdivisions of past time that we choose to make must be arbitrary. In those portions of the stony record which have been best preserved, this very difficulty of subdividing presses upon us—we find it often hard to say where a so-called period ends and another period begins. For it is evident that the germ, as it were, of one period must have begun in the period that preceded. Nevertheless, it becomes evident, on a broad view, that the organised beings that existed during some prolonged epoch of past time, have a certain *facies* which serves to distinguish them in the mass from the living things that flourished in preceding and succeeding ages; just as one can see, from the perusal of human history, how the manners and customs of the middle ages indicate a type of civilisation differing from that of ancient Rome on the one hand, and that of the Victorian era on the other. It is quite true that only fragments of the former life of the globe have been preserved—that numerous gaps in the succession of the fossiliferous strata occur—enough, however, remains to shew how strongly contrasted was the life of widely separated periods of time.

14. *Divisions of Strata, &c.*—Geologists generally subdivide the fossiliferous strata into—(1) Palæozoic or Primary, (2) Mesozoic or Secondary, (3) Cainozoic or Tertiary, (4) Quaternary or Post-Tertiary formations. The oldest formations are the Palæozoic or Primary; they are distinguished by their peculiar *ancient* types of animals and vegetables. In the Mesozoic or Secondary formations are found a widely different assemblage of plants and animals—forming the *mediæval* life of the world. The Cainozoic or Tertiary formations are characterised by the presence of faunas and floras more nearly allied to those of the present day—in the latest beds of the Tertiary many of the forms being living

species. All deposits of later date than the Tertiary are described as Post-Tertiary or Quaternary, although it would be more scientifically exact, perhaps, to abolish this subdivision, and include the strata under some other name, as Tertiary deposits. Under these larger divisions are grouped the various great formations which geologists have been able to separate from each other by more or less well-defined lines. It must not be supposed, however, that these formations are either of the same relative thickness, or that they represent periods of time of corresponding length. The geologist, as a rule, takes advantage of breaks in succession —of unconformabilities and so forth, to draw his lines of demarcation—and thus his 'formations' may differ to any extent in thickness and the length of past time which they represent. Sometimes, when he has no unconformabilities, &c. to help him, the geologist is guided by the fossils alone in forming his subdivisions—as we shall see is the case with the Tertiary formations. The larger divisions and subdivisions are given in the following table in the order of superposition—the oldest known occupying the bottom, and the youngest the top :

IV. QUATERNARY OR POST-TERTIARY—
- Neolithic and Recent.
- Pleistocene and Palæolithic.

III. TERTIARY OR CAINOZOIC—
- Pliocene.
- Miocene.
- Eocene.

II. SECONDARY OR MESOZOIC—
- Cretaceous.
- Jurassic.
- Triassic.

I. PRIMARY OR PALÆOZOIC—
- Permian.
- Carboniferous.
- Devonian and Old Red Sandstone.
- Silurian.
- Cambrian.
- Laurentian or Pre-Cambrian.

A short account of each of these formations,* as developed in Britain, now falls to be given.

PRIMARY OR PALÆOZOIC FORMATIONS.

LAURENTIAN.†

15. In the Hebrides, and in the north-west Highlands of Scotland, is found a great succession of highly inclined gneissic strata, which are here and there cut through by granite. These strata being covered unconformably by Cambrian rocks, are undoubtedly the oldest stratified rocks in Britain. An immense thickness (30,000 feet) of gneissic rocks occupies a similar geological horizon in Canada, where the beds have been termed 'Laurentian' by Sir W. E. Logan; with these the Scottish rocks are supposed to be contemporaneous. The Scottish Laurentian strata contain here and there inconsiderable seams of apparently unfossiliferous ironstone and limestone; but in Canada the limestones are thick, and have yielded one—the oldest known—fossil, *Eozoon Canadense*, believed to be a large foraminifer, which seems by its growth to have formed reefs of limestone. No other organic remains are met with in the Laurentian rocks in Scotland or in America, but similar foraminifers occur in rocks occupying the same relative position in Bohemia and Bavaria. Whether fossils were ever more abundant in these oldest known strata we cannot tell. The whole series is highly metamorphosed—the original deposits of sand and mud having been changed into crystalline rocks—and during the process of metamorphism any fossils which did exist must have been obliterated. Thus, we cannot be sure that we have yet met with the beginning of life upon the globe. The Laurentian strata were derived from the disintegration of still older rocks, and may at

* The term 'system' is often used alternatively for 'formation,' while again many of the subdivisions of a formation are themselves termed *formations*. See par. 5.

† From the river St Lawrence in Canada, north of which the strata are greatly developed.

one time have been abundantly charged with plant and animal remains. We can draw no conclusion with regard to the climate or the conditions of life that characterised the northern hemisphere during the accumulation of the Laurentian strata.

CAMBRIAN.*

16. This formation is represented in Wales and Shropshire by a great thickness (between 20,000 and 30,000 feet) of coarse red and purple sandstones and conglomerate, and some grayish-blue slaty shales, which are highly metamorphosed in some parts of Wales. Along the sea-board of the North-west Highlands occurs, on the same geological horizon, a thickness of 7000 or 8000 feet of red and purple sandstones and conglomerates; while in Ireland, the Cambrian rocks are represented by great masses of strata closely resembling rocks of the same age in North Wales. Very few fossils occur. None has yet been found in the Scottish Cambrian, but in the English and Irish strata obscure worm-tracks and burrows, and other markings, have been observed, the most noted of these being *Oldhamia* (fig. 1)—the nature of which, whether plant or zoophyte, has not yet been determined; and at St Davids, in Wales, strata of Cambrian age have yielded a number of crustacea (trilobites and phyllopods), brachiopods, pteropods, and worm-tracks.

1. Oldhamia antiqua.

17. The Cambrian strata rest quite unconformably upon the Laurentian rocks. We can form no decided conclusions as to the physical conditions under which the Cambrian strata were accumulated. The only recognisable fossils are marine, but it seems not unlikely that in some places the strata may be of fresh-water origin. We can say nothing positive about the climate of Cambrian times.

* This name was given by Sedgwick to strata in North Wales, some of which, however, were afterwards included under the Silurian formation.

SILURIAN.*

18. The Silurian strata are typically developed in Wales, and consist of two great series, *lower* and *upper*, the latter resting unconformably upon the former. In Wales and Shropshire the Lower Silurian are composed of five groups, each of which has received a distinguishing name. The rocks consist of grits, slates, dark shales, flags, sandstones, and conglomerates, and interbedded with these occur occasional calcareous bands, and at least one well-marked limestone seam, upwards of 20 feet thick, called the 'Bala limestone.' The whole series attains a thickness of 18,000 feet, distributed as follows :

	Feet.
5. Lower Llandovery rocks	1000
4. Bala beds, or Caradoc rocks	6000
3. Llandeilo flags	5000
2. Tremadoc slates	1000
1. Lingula flags	5000

19. The bottom beds—namely, the Lingula flags—graduate down into the underlying Cambrian rocks quite conformably, so that there is really no physical break between the Silurian and Cambrian systems. It is believed, however, that there is such a break between the Lingula flags and the overlying groups, partly upon physical, and partly upon palæontological evidence, for the fossils of the Lingula flags differ a good deal generically, and still more so specifically from those in the strata above them. Hence, some geologists would separate the Lingula flags from the Silurian, and include them among the Cambrian strata. The Upper Silurian rocks of Wales rest unconformably upon the lower group. The break is marked not only by unconformability and the overlap of the upper upon the lower group, but also by a change in the fossils. The typical subdivisions of the Upper Silurian are as follows :

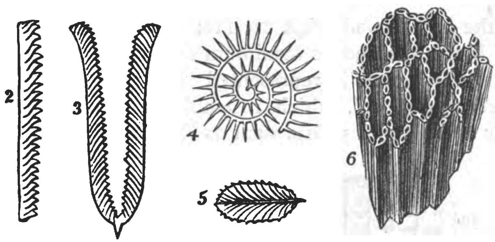
* So called from an old British tribe, the Silures, who inhabited part of South Wales, where this formation is well developed.

		Feet.
	Tilestones (passage beds up into Old Red Sandstone)	1000
3. LUDLOW GROUP	Upper Ludlow beds (with Bone bed)	900
	Aymestry Limestone	150
	Lower Ludlow beds	900
2. WENLOCK GROUP	Wenlock limestone	150
	Wenlock shale, sandstone, and flags	1400
	Woolhope limestone and shale (Denbighshire grits, shales, slates, and flags)	150
1. LLANDOVERY GROUP	Tarannon shale (pale slates)	600
	Upper Llandovery rocks or Mayhill sandstone	900

20. The Silurian strata which are so typically developed in Wales and the adjacent districts of England, are also well exposed in the Lake District of the north of England, where both the lower and upper series are seen. In Scotland, rocks of Silurian age form by much the largest part of that country—for, with the exception of a strip along the sea-board in the north-west, a broad patch in Caithness, and the belts of low ground that border the Moray Firth, the whole of the mainland, southwards to a line drawn from Helensburgh to Stonehaven, is composed exclusively of Silurian rocks and associated masses of granite, syenite, &c. And in like manner the Southern Uplands which extend from the hills of Carrick and Galloway in the south-west, to the Lammermuir Hills, and the heights drained by the river Tweed and its tributaries in Selkirk and Roxburgh shires, are made up entirely of Silurian strata—only a few inconsiderable patches of younger strata occurring here and there. Notwithstanding this great development of Silurian rocks, it is remarkable that the upper series is almost unknown—occurring only in a few localities in the south of Scotland, while in the northern Highlands it seems to be absent. In this latter region, where the whole series is more or less metamorphosed—consisting of thick successions of gneiss, mica-schist, and other allied rocks, underlaid by quartz rocks and limestones with Silurian fossils—it is quite possible that we may have some equivalents of the

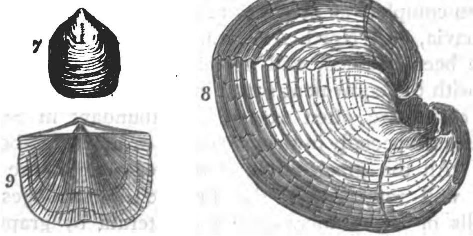
Upper Silurian strata, which the highly altered character of the beds prevents us recognising. Silurian strata are also abundantly developed in Ireland, large tracts in the north and west being metamorphosed. Both upper and lower groups are well represented, but the succession is by no means so complete as in Wales and England. In Bohemia, Scandinavia, and North America, the Silurian strata have likewise been studied, and correlated, by means of their fossils, with the equivalent strata in Britain.

21. Fossils are often exceedingly abundant in Silurian rocks, more especially in the calcareous or limestone-bearing groups. All the great sub-kingdoms of animals are more or less well represented—the Protozoa by sponges and the shells of foraminifera—the Cœlenterata by graptolites and corals. The fossils called *Graptolites* (figs. 2, 3, 4, 5)



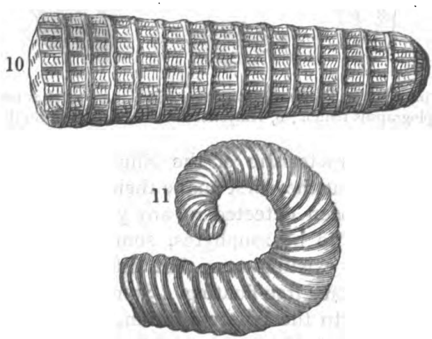
2, Graptolites priodon; 3, Didymograpsus Murchisoni; 4, Rastrites peregrinus; 5, Diplograpsus folium; 6, Halysites catenulatus (chain coral).

are eminently characteristic of the Silurian—for it is in rocks of this age that they first make their appearance, and they have not yet been detected in any younger formation. They are believed to be zoophytes, somewhat resembling the sertularians of existing seas, but differing from them in having the polypary free-floating. Some species of graptolites are confined to the Lower Silurian, and others again, while occurring in the lower group, are most abundantly met with in the Upper Silurian. Among the corals, which are very abundantly distributed through the Silurian strata, one of the most commonly occurring forms is the 'chain coral' (fig. 6). So plentiful are corals in some places that they seem to form the bulk of the rock, and may possibly represent ancient coral reefs, as, for example, in the case of the Wenlock limestone. Among the mollusca the most abundant forms are the brachiopods (figs. 7, 8, 9), and after



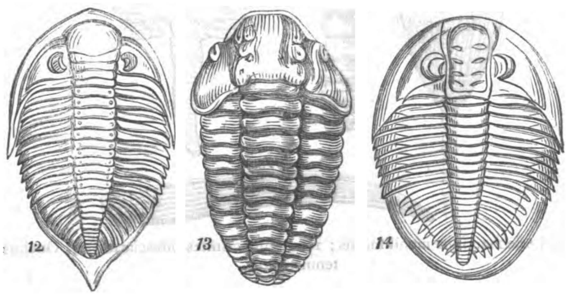
7, Lingula Davisii; 8, Pentamerus Knightii; 9, Orthis vespertilio.

these the cephalopods (figs. 10, 11): indeed, one great group of the latter attained its maximum development in Silurian times. This group is represented by numerous species of *Orthoceras* (fig. 10), which resembles a nautilus uncoiled, and by coiled species also, such as *Lituites* (fig. 11). Some



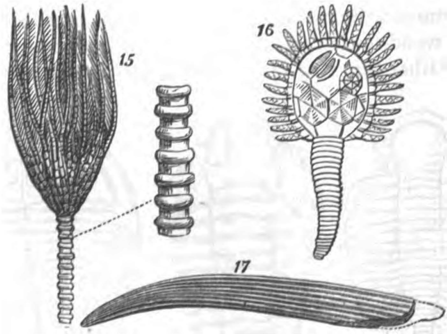
10, Orthoceras annulatum; 11, Lituites giganteus.

of the most noted Silurian brachiopods and cephalopods are shewn in the annexed figures. The annulosa are represented by numerous forms of crustacea, echinodermata, and by the tracks, burrows, and spiral tubes of various species of annelida; but no traces of insects, myriapods, or arachnids have yet been detected. The most characteristic fossils are trilobites, which, although they make their first appearance in Cambrian strata, and lived on into Devonian and Carboniferous times, yet reached their greatest development in the Silurian age. There are very many genera and species of these remarkable crustaceans, and almost every subdivision of the strata has its own characteristic types. The trilobites (most of which possess compound faceted eyes, although some seem to have been blind) had the body usually divided into three regions—namely, a cephalic (head) portion, generally in the form of a semicircular plate or shield; a thoracic region, distinctly segmented; and a caudal shield formed by the union of the abdominal segments. Owing to the flexibility of the thoracic segments, the creature could coil itself up, much as the common wood-louse can. The figures shew some common forms. Other types of crustacea appear in Silurian strata,



12, Phacops caudatus; 13, Calymene Blumenbachii; 14, Ogygia Buchii.

but the trilobites are by far the most abundant and characteristic of the system. Among the echinodermata, which are well represented, the most numerous are crinoids and cystideans. Crinoids, or sea-lilies, are still represented in modern seas. A crinoid consists of a longer or shorter jointed or flexible stalk fixed to the sea-bottom during the whole or a part of the creature's existence, and supporting a cup-shaped body, formed of calcareous plates on the under or convex part —the upper side being closed by a coriaceous or leathery skin. From the margins of the cup-shaped body, where the upper leathery part and the lower calcareous portions unite, spring five or ten jointed flexible arms, which, however, are often branched higher up. These arms are provided with slender jointed appendages (cirri), which are also highly flexible. The arms and cirri, by their movements, cause little currents in the water, by which means food is brought to the mouth, in the centre of the upper disc of the body. Fig. 15 represents a Silurian crinoid. The cystideans are all quite extinct. Like the crinoids they were fixed by a stalk which supported a globular or pear-shaped body. But this body was completely inclosed in calcareous plates, and as a rule was not



15, **Periechocrinus moniliformis**; 16, **Pseudocrinites bifasciatus**; 17, **Onchus tenuistriatus.**

furnished with arms like the crinoid. In some species, however, we find short jointed arms, as in the specimen figured here (fig. 16). The tubular burrows of sea-worms are often observed in the strata, as are also the tracks of annelids on the surfaces of beds. Occasionally, too, we get the tubular cases of certain annelids attached to shells and other fossils. The Upper Silurian furnishes the geologist with the oldest known vertebrates. These consist exclusively of fishes, represented mainly by external plates and defensive spines (fig. 17), which were discovered in the Ludlow rocks. Some of the fishes, from the character of their remains, appear to have been predaceous, like the existing Port Jackson shark and the dog-fishes of our own seas; while others would seem to have had their heads covered with external bony plates—a character which, as we shall afterwards see, was highly developed among the fishes of the succeeding Old Red Sandstone and Devonian period.

22. Plant-remains consist almost exclusively of fucoids, represented by more or less obscure markings: sometimes these are very abundant, and it has been suggested that the beds of anthracite occasionally met with in Silurian strata may owe their origin to immense accumulations of such sea-plants. Traces of true land-plants are extremely rare, and such as have been met with belong to extinct species related to the club-mosses and ferns, and coming therefore under the class of acrogens.

23. The Silurian formation, then, is eminently marine, and affords evidence that during its accumulation vast tracts of the present continents were covered by the waters of the ocean. The temperature of the sea in those ancient times would appear to have been remarkably equable, so as to have allowed of the dissemination of the same or closely analogous species of molluscs, crustaceans, &c. over vast regions—characteristic Silurian fossils having been obtained from the frost-bound shores of Northern Greenland and other arctic countries. But while some of these arctic fossils are identical with those of the English Silurian strata, yet it must be noted that the general aspect of the arctic Silurian fauna is rather American than European. The character of these fossils affords strong proof of a mild climate having prevailed in polar regions during Silurian times—for although the fossils belong to entirely extinct species, yet the fact that they consist largely of corals and chambered shells (the modern representatives of which are confined to southern and warm latitudes), and the further consideration that the same or closely analogous species occur in Silurian strata in low temperate latitudes, are proof presumptive that the arctic seas in those days

were mild and genial. Nevertheless evidence of ice-action in Silurian times is not wanting; for large *erratics*, or wandered blocks, of gneiss, syenite, &c., apparently ice-carried, occur in fine-grained Silurian rocks in the south of Scotland, and proofs of the former action of frost have also been detected in the Silurian strata of North America. It is quite possible that during the Silurian age, which must have endured for many thousands of years, there were several great changes of climate, brought about by certain cosmical causes to which more particular reference will be made in the sequel.

24. During the accumulation of the British Silurian strata, volcanic action manifested itself in Wales at two separate periods. While the Llandeilo rocks were being deposited as sediment, lava flowed out in wide sheets over the sea-bottom, preceded and succeeded often by showers of stones and dust, which fell into the water, mingling with the other sediment, and covering up shells, corals, and other organisms. Volcanic action then ceased for a long time, but again burst out during the formation of the Bala beds. Volcanoes also existed in what is now the Lake District. In Scotland there is no trace of Silurian volcanoes, but such is met with in Ireland, among the headlands of Kerry.

DEVONIAN AND OLD RED SANDSTONE.*

25. The Devonian strata are divided in Devon and Cornwall into lower, middle, and upper groups. But the strata of that district are often much contorted. The upper group consists of slates, schists, calcareous bands, quartzites, and red and green sandstones. The middle group is made up of coarse red sandstone, flagstone, schists, calcareous slates, and limestone; while the lower group comprises red sandstones and conglomerates, that rest upon schists and slates, the base of which is not seen. The fossils of the upper group

* So called because well developed in Devon. The alternative title of 'Old Red Sandstone' is usually confined to the red sandstones and conglomerates which in Wales, Scotland, and Ireland, occupy the same relative position as the Devonian strata of the south of England—namely, intermediate between the Silurian and Carboniferous strata.

occur also in the Carboniferous formation. With the exception of a few land-plants, all the fossils obtained from the Devonian rocks of Devon are marine, and consist of molluscs, representing most of the great classes, annelids, crustaceans, cup-corals, &c. With these strata are correlated the Devonian strata of Rhenish Prussia. In North America the strata lying between the Silurian and Carboniferous systems are more typically developed than anywhere else: they are all of marine formation, and contain in their upper portions numbers of fossils which pass up into the overlying Carboniferous deposits; while, in the middle and lower members of the series, not a few Silurian forms are met with, thus shewing that the whole series is truly of intermediate age between the Silurian and Carboniferous.

26. In Wales, Scotland, and Ireland, we meet with no strata exactly corresponding to the marine Devonian formation as developed in Devon, on the continent, and in America. But occupying precisely the same stratigraphical position or horizon, there appear great masses of red sandstone and conglomerate, which still retain the name first given to them by the coal-miners, who called them the 'Old Red Sandstone,' to distinguish them from the thick red sandstones that lie above all the coal-bearing strata, and which are known to the miners as the 'New Red Sandstone.' The reader must not imagine, however, that all the strata included under either designation are red—many are gray, dark green, yellow, purple, or chocolate-brown, &c.—oftentimes, too, the strata are not composed of sandstone. The names applied to the various members of the fossiliferous strata had originally in many cases a local significance, but such names having once become current, were necessarily applied subsequently to rocks which, although of the same age, yet frequently differed very much from those first described. Thus when a geologist speaks of 'Greensand' beds, he simply means certain strata that belong to the Cretaceous formation, which may or may not consist of green sand. In short, such terms are merely *names*, and not *descriptions*.

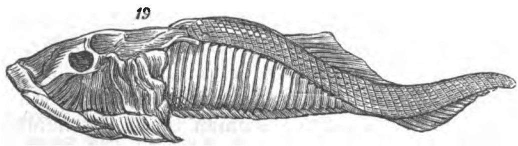
27. It is in Scotland where the Old Red Sandstone is most

typically developed. The formation comprises three groups —lower, middle, and upper. In the districts south of the Grampians the strata consist chiefly of red sandstone and conglomerate, with marly argillaceous shales, &c., and contain here and there land-plants and fish-remains, especially in Forfarshire. In Northern Scotland, red sandstones and conglomerates also occur, but the middle group consists chiefly of gray and dark flagstones, which contain numerous fish-remains. In Southern Scotland, the middle group rests unconformably upon the lower, and is covered unconformably by the upper group. Contemporaneous volcanic rocks are common in the middle and lower groups of the same district, but are wanting in the north.

28. The upper group in Southern Scotland passes up conformably into the Carboniferous, while the lower one passes down conformably into the Upper Silurian strata. In England, the Old Red Sandstone of the districts adjoining Wales in like manner passes down conformably into the Upper Silurian, and the same appears to be the case in Ireland. In the latter country, we find a great break in the succession of the strata, like that in the Old Red of Southern Scotland, and an upper set of red sandstones (which are quite conformable to the overlying Carboniferous system) resting unconformably upon a lower set (called the Dingle Beds), which graduate downwards, as just stated, into the underlying Silurian. Fossils do not often occur in the English and Irish strata, and those which have been found consist principally of fish-remains and some crustaceans. The Irish deposits have yielded some fine land-plants, and a bivalve closely resembling the anodon or fresh-water mussel of existing lakes and rivers. But by far the most characteristic fossils of the Old Red Sandstone are the fishes. So abundant are these, that the period during which the Old Red strata were deposited has been called the 'Age of Fishes.' Most of the species, which are numerous, come under the order of the ganoids. These were all more or less completely cased in a strong armour of enamelled bone, consisting generally of rhomboidal plates arranged in oblique rows. In some species, the large plates

that covered the head were immovably united together so as to form a shield or buckler; while in others this strong casing of bone extended over the whole of the head and the major portion of the body (see figs. 18, 19). As the internal skeleton was only partially ossified, the ganoid fishes are known to us chiefly through their plates, scales, and teeth, which in some of the species were of two sizes. The ganoid order of fishes, so abundant in Old Red Sandstone times, is now represented by only two or three species, such as the Garpike (*Lepidosteus*) of North America, and the *Polypterus* of the Nile. The 'Old Red' ganoids

18, Pterichthys.



19, Cephalaspis Lyellii.

were of all sizes—some like small trouts, and others reaching a length of between twenty and thirty feet. Besides ganoids, there occur in the 'Old Red' strata the crushing teeth and defensive spines of large cestracionts; these fin-spines are called *ichthyodorulites*.

29. This rapid glance at the two types of strata—the Devonian rocks of Devon, and the Old Red Sandstone of the more northern districts—will suffice to shew the student how much they differ. The Devon beds are exclusively

marine, being in places abundantly charged with marine organisms, while in the Old Red Sandstone no undoubted marine fossils have been detected; only land-plants, a probably fresh-water shell, and numerous fishes which, like existing ganoids, may have frequented rivers and lakes. These and other considerations have led some geologists to believe that the Old Red Sandstone strata were deposited in great fresh-water lakes into which, perhaps, the sea may sometimes have got access; the Old Red Sandstone, therefore, might quite well be the equivalent of the marine Devonian beds, just as the deposits taking place in Lake Superior are the equivalents of the sediments that are now accumulating upon the bed of the Atlantic. Of course it does not necessarily follow that the Old Red Sandstone and the Devonian strata of Devon are precisely contemporaneous. They may represent different portions of the same great period—or one may represent only a fraction, while the other represents the whole. It is worth noting that Old Red Sandstone fishes occur pretty often in the American Devonian, and are also met with in the same formation in Rhenish Prussia—the strata in both these regions being marine. This would seem to shew, that the ganoids and cestracionts of those old times may have frequented both fresh and salt water, like many fishes of our own day.

30. The general character of the Devonian fossils implies a mild climate. Many of the trilobites so abundant in Silurian seas lived on into Devonian times, but numbers of genera and species had already become extinct. Corals were plentiful, as were also chambered shells, and such land-plants as have been discovered favour the inference that the climate under which they flourished was mild. From certain appearances, however—such as the presence of thick coarse conglomerates, some of the stones in which exhibit scratched and smoothed surfaces such as might have been the work of glacier ice—it has been inferred that, at some time during the accumulation of the Old Red Sandstone strata, the climate of the British area was cold enough to nourish glaciers, which flowed down from mountain-valleys into great lakes. Much of the Old Red Sandstone conglom-

erate, indeed, strongly resembles the moraine matter and coarse shingle of alpine regions. In fine, the evidence would lead us to infer that during the Devonian or Old Red Sandstone period the sea covered over the southern parts of what is now England, while to the north existed land largely covered, in Scotland, with lakes (some of which may have communicated with the sea), fed by streams and rivers that flowed from what are even now the chief mountain-districts. Here and there in Scotland—as, for example, in Ayrshire, in the Cheviot district, and in the regions of the Ochil and Sidlaw Hills—there existed, at various times throughout the period, active volcanoes, from which sheet after sheet of molten lava and showers of stones and dust were ejected, and some of these eruptions appear to have been sub-aërial. Nor was volcanic action confined to Scotland, for masses of trap-tuff occur in the Irish Devonian; and in Devon itself there were submarine volcanoes. It is probable, moreover, that the climate was not throughout a genial one, but that one or more cold periods intervened during the epoch.

CARBONIFEROUS.

31. The Carboniferous * formation is well developed in the British Islands. It covers wide areas in Wales, and the midland and northern counties of England. In Scotland, broad areas of it extend over a great portion of the lowlands that stretch across the country from sea to sea, between the Grampians and the Southern Uplands; while in Ireland Carboniferous strata occupy the largest portion of the country. The formation consists of the following groups, which are more or less persistent over the British area, but differ very much in character in the various districts:

4. Coal-measures.
3. Millstone Grit.
2. Carboniferous or Mountain Limestone.
1. Lower Limestone Shale, and Calciferous Sandstone series.

32. The lower group passes down conformably into the

* So called from the abundance of its intercalated coal-seams.

Upper Old Red Sandstone, when that happens to be the underlying formation; but it is very often absent, and then the strata rest unconformably upon one of the lower divisions of the Old Red Sandstone, or upon still older Palæozoic rocks. In England and Ireland, this group appears to be entirely marine. In Scotland, however, it would seem to be upon the whole of lacustrine and estuarine origin, with here and there more evident marks of the former presence of the sea. It is this group which in Scotland yields the 'oil-shales.' These shales occur in the upper part of the group interbedded with black and blue shales, gray and white sandstones, and occasional fresh-water limestones and coal-seams. The lower part of the group in Scotland usually consists of red and purple sandstones and conglomerates. In the English and Irish areas, the group is made up of dark earthy shales and slates, with thin flaggy limestones above, and containing in their lower portions yellow sandstones, or gray and green grits, &c.

33. The Carboniferous or Mountain Limestone is a very variable group. Sometimes it is composed almost entirely of limestone; at other times the limestone alternates with strata of sandstone and shale. Occasionally, as in some parts of Scotland, the separate seams of limestone are only a few feet in thickness, while in other places the limestone forms a solid mass more than fifteen hundred feet thick. In South Wales, the group is made up chiefly of limestone, associated, in some places, with sandstone and shale, and averaging from five hundred to fifteen hundred feet in thickness. Again, in the north of England and North Wales, the same group is largely developed (one thousand to four thousand feet), while in the midland counties it is much dwarfed, and often entirely wanting. In Ireland its maximum thickness is three thousand feet, probably not much less than two thousand feet of which are pure limestone. As we trace the English Carboniferous Limestone series into Scotland, we find the massive limestones becoming more and more split up or divided with intercalated beds of sandstone and shale, and occasional coal-seams, until eventually the limestone-seams come to form a very in-

considerable part of the group, so far as bulk is concerned. In the Scottish districts, accordingly, the group divides itself into three series—the upper consisting chiefly of sandstones with three or more seams of limestone; the middle made up of sandstones and shales, with numerous seams of coal and ironstone, but no limestone; the lower comprising sandstones and shales, with interbedded coal and ironstone seams, and several beds of limestone. The Scotch limestones are generally only a few feet each in thickness, three to six or nine feet being a common thickness. Occasionally, however, they may exceed one hundred feet. The Scotch, Irish, and English limestones of this series all agree in being of marine origin. In some parts of England, a series of strata of sandstones and shales, with thin limestones and occasional coals (called the Yoredale series), comes on top of the great Mountain Limestone group. The Yoredale series varies in thickness from five or six hundred feet to four thousand five hundred feet.

34. The Millstone Grit consists principally of sandstones, which are sometimes coarse-grained and hard. It is exceedingly variable in thickness—in England varying from two or three hundred to five thousand five hundred feet, and in Scotland being sometimes as thin as fifty feet. Occasionally it contains thin limestones and shales, and thick fire-clays and thin coals.

35. The Coal-measures comprise a vast thickness of sandstones and shales, intercalated among which occur more or less numerous seams of coal, varying from an inch or less up to beds several yards in thickness. In South Wales, the series reaches a thickness of nine thousand six hundred feet, which appears to be the maximum in Britain. In England, the workable coals are mostly confined to the Coal-measures, but some occur in the Millstone Grit and Carboniferous Limestone groups of the northern districts. In Ireland, likewise, some of the seams appear to belong to the Millstone Grit series. In Scotland, coals are worked not only in the true Coal-measures, but generally in the Limestone group also, which has yielded the best gas-coal seams and some excellent blackband-ironstones. Good

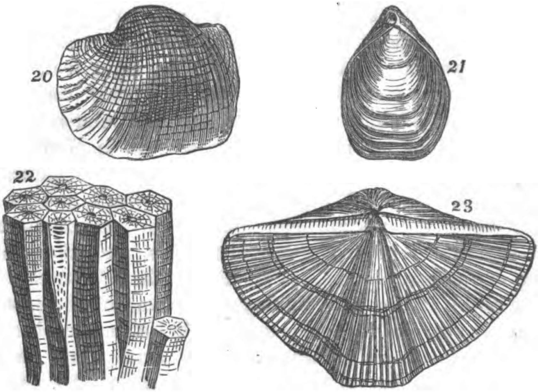
coals also occur in the Lower Carboniferous or Calciferous Sandstone group of Edinburghshire and Fifeshire. A group of red sandstone strata rests unconformably upon the true Coal-measures in some of the Scottish coal-basins.

36. Volcanic rocks are often associated with the Carboniferous strata. They are both contemporaneous and intrusive. In Scotland, the former occur in all the groups, with the exception of the true Coal-measures; in England and Ireland, they appear to be restricted, for the most part, to the Carboniferous Limestone, but in Cornwall and Devon, they occur towards the base of the Carboniferous strata.

37. Carboniferous strata occur on the Continent in various countries, but are not so well developed as in Britain. Among the most noted of European coal-fields are those of Belgium and Valenciennes, in the north of France. Other French coal-fields are those of St Etienne, St Germain, Auzon, and Donjon. One of the largest coal-fields of Western Europe is that of Rhenish Prussia, comprising about nine hundred or one thousand square miles. Coal-fields also occur in Westphalia, Bohemia, Silesia, Russia, Spain, and Portugal. Carboniferous strata are strongly developed in North America, especially in Nova Scotia, New Brunswick, and the United States. The Appalachian coal-field in the latter country has a superficial area of at least sixty-three thousand square miles. Throughout a considerable part of this great coal-field the strata are contorted, and in such disturbed regions the coals are generally more or less anthracitic. To the Carboniferous system have been referred coal-fields in India and Australia.

38. The fossils of the Carboniferous system are very abundant—both animals and plants. Foraminifera and sponges represent the Protozoa, and an abundance of corals (fig. 22), the Cœlenterata. These are specially plentiful in some of the limestones, and appear, indeed, often to compose the bulk of the rock. Mollusca (figs. 20—23) were exceedingly numerous in the Carboniferous seas. Polyzoa, in profusion, spread their delicate network over corals and dead shells. Brachiopods and lamellibranchs were like-

wise exceedingly abundant; gasteropods, pteropods, and cephalopods were also represented. Among Echinodermata, stone-lilies occur often in great profusion, certain limestones appearing to be made up almost entirely of their remains. Sea-urchins are also met with. Annelids

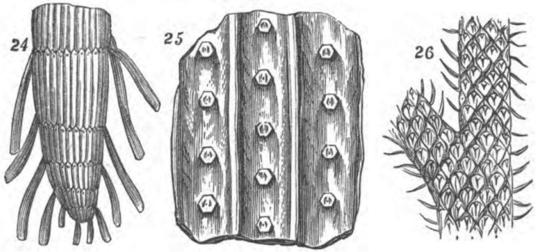


20, Producta semireticulata; 21, Terebratula hastata; 22, Lithostrotion basaltiforme; 23, Spirifera striata.

are sometimes very common, and their tracks are frequently seen on the surface of fine-grained flagstones. Crustaceans are represented by several orders—some, which had appeared in earlier ages, now dying out for ever. Trilobites, for example, seem to have become extinct in Carboniferous times. Arachnids and insects (namely, extinct forms of scorpion, beetles, and dragon-fly) have been detected; and in the coal-field of Nova Scotia, a large ephemera, and a myriapod resembling the recent centipede, have been found—the latter along with reptilian remains and land-shells; fossil scorpions and spiders occur in the Coal-measures of Bohemia and Silesia. In the German coal-fields, extinct species of cockroaches, beetles, grasshopper or locust, cricket, and white ants, have been found. The Vertebrates are represented in the British strata by numerous fish-remains—some of them ganoids, others allied to the modern sharks. One of the most formidable of the ganoids (*Rhizodus*), furnished with large conical incurved teeth, seems to have attained a great size. Among its congeners were numerous cestracionts, with broad crushing teeth, and defensive fin-spines. Besides fishes, the Carboniferous strata have also yielded the remains of a number of genera of amphibians, some of which seem to have attained a length of seven or eight feet, while others did not exceed as many inches. They resembled in shape the existing salamander, and had relatively weak limbs and a long tail; and the inferior surface of the body was protected by a bony armour, consisting of numerous long plates disposed in oblique rows, which met at an angle along the middle line. The teeth were numerous, and sometimes of large size like tusks, and they shew, when cut across, a complicated 'labyrinthine' pattern, due to the rapid folding and plaiting of the wall of the tooth—hence the name of the order under which these amphibians are ranged—*Labyrinthodonta.* The skull was shaped somewhat like that of the crocodile, and like this animal, the labyrinthodonts appear to have been predaceous. They seem to have frequented the rivers of the old Carboniferous land, and to have lived on fishes, insects, and myriapods, the larger labyrinthodonts sometimes devouring smaller species of amphibians, as the bones met with in their coprolites (fossil droppings) would seem to shew. Occasionally, the foot-prints of labyrinthodonts are detected upon the surfaces of flagstones and sandstones—the impressions having some resemblance to those of a human hand with the fingers extended.

39. But the most characteristic of Carboniferous fossils are plants, which occur in extraordinary abundance. By far the great majority of these belong to the cryptogamic division—the most marked consisting of ferns, lycopods, and calamites. But besides these, there were gymnosperms, comprising conifers, and perhaps cycads and the curious sigillariæ. No angiosperms occur, and very few flowering plants have been detected.

40. Ferns are extremely abundant, and comprise both herbaceous and arborescent forms.—*Calamites* (fig. 24) are also very plentiful. They seem to have been a kind of gigantic horse-tails. They were 'slender, ribbed, and jointed externally, and from the joints there proceeded, in some of the species, long narrow simple branchlets; and in others, branches bearing whorls of small branchlets or rudimentary leaves.' The stem was hollow, and had neither true wood nor bark. Calamites grew in dense brakes on low alluvial flats, and perhaps even in water. To support themselves, they



24, Calamites cannæformis; 25, Sigillaria lævigata; 26, Lepidodendron Sternbergii.

threw out cord-like roots from the lower part of the stem. Some calamites reached a length of thirty feet.—*Lepidodendra* (fig. 26) were large arborescent plants, apparently allied to the existing lycopods or club-mosses. The stems are covered with leaf-scars, arranged in quincunx order, and in their mode of branching are dichotomous or regularly bifurcating. Most of the existing club-mosses trail or creep on the ground, but the extinct lepidodendra grew erect to a height in some cases of sixty feet. They are among the most abundant fossils of the Carboniferous strata. The seed-cones of the lepidodendra are called *Lepidostrobi*, and are not uncommon fossils.—*Sigillariæ* (fig. 25): These were tall trees (thirty to sixty or seventy feet) of somewhat uncertain affinities—some botanists maintaining their cryptogamic and others their phanerogamic character. They seem to present characters intermediate between gymnospermous exogens and the higher acrogens. Their stems were fluted and marked with little scale-like impressions, or marks left by the base of the leaf-stalks which have fallen off. When lying horizontally in the strata, the coal-trees are generally squeezed quite flat, particularly in the case of the calamites and sigillariæ—these latter having through internal decay become hollow while standing, were easily crushed down, and flattened when they fell.—*Stigmariæ* (fig. 27) are the roots of *Sigillariæ* and *Lepidodendra.* They are a very common fossil, especially

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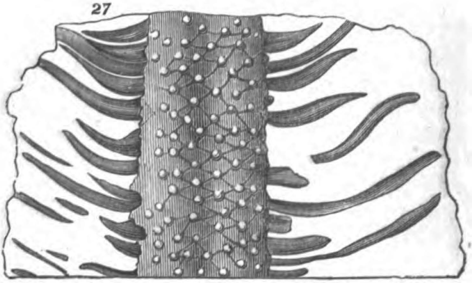


27, Stigmaria ficoides.

in the 'underclays,' upon which most coal-seams repose. They occur as long rounded or somewhat flattened arms, dotted with numerous rounded pits, or tubercles, from which proceed long cylindrical rootlets. These last, however, are often wanting—many underclays, however, are literally crammed with them.—*Coniferæ,* some of which seem to be allied to the modern araucarians, have been recognised, but they are not so abundant as any of the preceding fossils. Nut-like fruits (*Trigonocarpum*) occur often in great profusion, and are conjectured to belong to conifers. It is doubtful whether cycads occur, although certain fossils have been considered to be cycadaceous. A flowering plant (*Pothocites*) has been obtained from the Scottish Carboniferous at Granton. It consists of a stem bearing a cylindrical spike—the exposed surface of which is covered with the calyces of the flowers in parallel rows. There can be no doubt that the fossil is monocotyledonous, and belongs to the order of *Aroidiæ*.

41. Coal-seams range in thickness from less than an inch up to fifteen feet and more; here and there a number of seams coming together, by the thinning out of the associated strata, to form masses not less than forty feet in thickness. Coal varies in character according to the nature of the plants of which it is composed; and we not unfrequently find one kind of coal shading into another, or even sometimes (in Scotland) into 'blackband-ironstone.' The trees and ferns that grew on dry land go to form 'common coal;' 'splint-coal' would appear to have resulted from a marshy vegetation; and 'gas-coal' has certainly been deposited as a black vegetable slime in lakes and lagoons, for it frequently contains fossils, fish-scales, cyprides, &c. 'Blackband-ironstone' has accumulated in the same way, and, indeed, it is often associated with gas-coal, and the one 'mineral' passes into the other. Clay-ironstone occurs both as regular seams and as scattered balls and nodules. In the former case, the mineral is due to deposition; in the latter, to segregation.

42. The physical conditions under which the British Carboniferous strata were deposited appear to have been as follows: About the commencement of the Carboniferous period, high ground existed in the north of Scotland, and in the Southern Uplands as well, from which it extended into the Lake District in the north of England. An irregular ridge of high ground seems also to have stretched through the midland district of England and North Wales, and to have continued westwards through the central region of Ireland. Between the Highlands and Southern Uplands of Scotland, and south from the Lake District, spread the waters of the sea, probably over all the English and Irish areas, save the ridge just referred to, which in those early times appears to have been a narrow rocky island. This was the condition of things during the deposition of the Lower Limestone Shale of England and the south of Ireland, and of the Calciferous Sandstone series of Scotland. In the latter country,

however, we find that the sea which covered what is now the central lowlands became in some places silted up, and passed into the condition of a low flat country abundantly intersected with numerous ramifying creeks, and lakes, and lagoons of fresh water or brackish water. Tree-ferns and other plants of tropical or sub-tropical aspect clothed the land, while the creeks and lagoons were slowly silted up with fine mud and decaying vegetable matter. In some of the deeper pools and lagoons a limy accumulation took place, in which were gradually entombed the remains of fishes belonging to wholly extinct species, some of which were allied to the great sharks of southern seas, and others to the bony-scaled polypterus and lepidosteus. Volcanoes were very numerous in Scotland during the deposition of the Calciferous Sandstone series. Most of these appear to have been submarine at first, but some of them existed for so long a time, and poured out so much material, that they became at last sub-aërial. Besides the large volcanoes of the hills of Haddington, Fife, Stirling, Renfrew, Ayr, &c., numerous little isolated volcanic ejections took place in the central lagoon region. About the same time there were submarine eruptions in the Devon and Cornwall district.

43. By and by, a great movement of depression supervened, and the rocky island in the central English and Irish districts slowly sank below the sea, until ere long deep water would appear to have covered all England and Ireland. This deep sea, however, shallowed somewhat gradually away to the north, and land may have existed in the extreme north of England, as it certainly did in the Southern Uplands and Highlands of Scotland. Corals and lily encrinites now swarmed, and shell-fish appeared in great profusion; and the slow disintegration of their exuviæ and skeletons, together with that of the shells and cases of minute foraminifera, gradually gave rise to great deposits of calcareous matter, which afterwards were to harden into limestone. The Scottish area at this period seems to have been subjected to considerable oscillations of level—sometimes all the low grounds being submerged, the sea ever and anon

penetrating far into the Uplands of the South, and probably into the Highlands also. At other times, the whole region stood above the sea-level, and dense and luxuriant growths of tree-ferns, lepidodendra, sigillariæ, and their congeners, took place. Again, the land disappeared below the sea, and the forests were overthrown and covered up with sand and mud. After such oscillations had been again and again repeated, a great succession of alternate beds of limestone, sandstone, shale, ironstone, and coal, was the result. Now, during all this time, the English and Irish areas had remained deeply submerged, calcareous deposits slowly accumulating the while. At the commencement of the Limestone period in Scotland, the volcanic forces displayed considerable activity in what is now Linlithgowshire, and some sporadic vents opened out on the sea-bottom in Fifeshire and Ayrshire. Similar submarine volcanoes appeared in Derbyshire; and in the sea which covered Ireland there were likewise occasional volcanic eruptions, the igneous rocks becoming intermingled with the calcareous deposits accumulating there.

44. After corals and encrinites had for long ages luxuriated in the clear waters of a deep sea, a great change eventually supervened. Vast heaps of sand were transported into the sea; the conditions became unfavourable to marine life, and the accumulation of the great limestones came to an end. The sandstones, &c. of the Millstone Grit indicate, upon the whole, a comparatively shallow sea; sometimes, indeed, estuarine conditions seem to have obtained at this time, and occasionally low flat lands would appear, and become clothed with greenery, only to sink again and receive a covering of mud and sand.

45. At last, however, terrestrial conditions prevailed, and the great vegetation of the Coal-measures overspread all the wide flat plains, which, during the Carboniferous period, seem to have extended continuously over vast areas. The appearance presented by a typical section of Coal-measures leads one to infer that the strata were slowly accumulated in the muddy deltas of vast rivers. We may conceive of a wide flat country covered with a dense growth of ferns, tree-

ferns, lepidodendra, sigillariæ, &c., with calamites clustering thickly along the shores of muddy rivers and lagoons. We see labyrinthodonts wading in the water for their prey, while great shark-like fishes ascend the rivers from the sea, and the waters swarm with innumerable mail-clad ganoids, some of them of most formidable dimensions. The chirp of the cricket and the hum of the beetle are heard in the forests, myriapods and cockroaches conceal themselves in the hollows of decayed trees, scorpions crawl about in search of insects, and dragon-flies dart up and down on a similar errand. Here and there a bright flower-covered monocotyledon lights up the glades; but the forests, upon the whole, are somewhat sombre. Whether any vertebrate animals haunted the forests, we cannot tell, for, after all, our knowledge of the life of the ancient Carboniferous land is singularly meagre. It is hardly possible that the few insects, arachnids, and myriapods which have been detected, adequately represent the terrestrial fauna, and we must hope yet to discover other forms and types.

46. The Coal-measures seem to have been laid down during a period of slow subsidence or depression of the land. But this movement may have been sometimes interrupted by long pauses, and occasionally even by a movement in the opposite direction. When the vegetation had by its growth and decay formed a great accumulation of carbonaceous matter, the low flat lands disappeared below the water, and were covered up with layers of mud and sand. When the surface of the old delta once more peered above the water, it again became clothed with greenery, which, after flourishing for untold years, was in like manner submerged and buried under mud and sand—a process which was again and again repeated. So that eventually numerous ancient land-surfaces with their vegetable coverings became entombed one above the other. As a general rule, it would seem that the strata lying between the coal-seams are of fresh or brackish water origin. The fossils they contain are just such as might have lived at one time in rivers, or opposite the mouths of rivers—as, for example, the anodon—which is so like the 'mussels' of existing fresh-

water areas. Then, generally speaking, the fossils that characterise the undoubtedly marine strata of the Limestone series seldom or never occur in the true Coal-measures. They have been met with, however, now and again, shewing that the fresh-water areas were liable occasionally to an influx of the sea. As far as we know, no volcanoes existed in the British area during the deposition of the Coal-measures. But at or towards the close of the period, melted rock was intruded in great sheets between the strata, in Scotland especially—none of this melted matter actually reached the surface.

47. The climate of Carboniferous times was singularly equable over a vast area—for coal with well-marked Carboniferous fossils occurs in the highest arctic regions—shewing that the climate of those regions did not differ much from that which characterised our own and even more southerly latitudes. The climate was not probably tropical, but genial—a warm summer like that of Southern England, and a very mild winter, with little or no frost at all. Indications of former ice-action have been noted in the Carboniferous strata of Scotland, Ireland, France, United States, Nova Scotia, Hindustan, and Australia.

PERMIAN.*

48. The Permian strata repose unconformably upon the Coal-measures when these happen to be the underlying rocks. They consist of two groups—lower and upper—as follows :

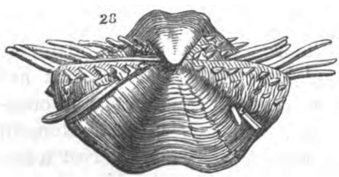
Lower group : consisting of red and purple sandstones, red marls, breccia, and conglomerate. The breccias are remarkable. They consist of angular fragments and occasional large blocks, weighing upwards of half-a-ton, of various rocks of older date than the Permian. Not a few of the stones are marked with grooves and striæ, like the scratched stones of glaciated regions ; some of the stones are far-travelled. Professor Ramsay believes these to have been transported by ice. Organic remains are generally

* A name proposed by Sir Roderick Murchison: from Perm, a Russian government in which strata of this age are largely developed.

absent, as is the case in most red sandstones. Here and there, however, in the red sandstones occur foot-prints of reptiles, and worm-tracks, and fragments of coniferous plants. In Scotland, volcanic rocks are often abundantly present—but the areas of Permian strata in that country are small and detached.

Upper group: consists principally of, first,* marl slate or shale, which contains occasional thin compact magnesian limestones; and, second, magnesian limestone—a very variable series of yellow and brown—fine-grained, compact, crystalline, brecciated, and earthy limestones. Some beds resemble piles of cannon-balls, or heaps of turnips, or bunches of grapes—others are quite oolitic. The fossils of this group are abundant, and all (with the exception of a few drifted land-plants) of marine species. The series is well seen upon the coast between the Wear and the Tees. In the north-west of England the magnesian limestones are very sparingly represented, but at St Bees' Head there occurs a set of red sandstones and marls with gypsum, which are the highest beds of the formation, and appear not to be represented in any other district in Britain. In Germany the Permian is composed of two members—the Zechstein and Kupfer-Schiefer, corresponding to the upper group; and the Rothliegendes, or Roth-todt-liegendes, representing the lower group of Britain.

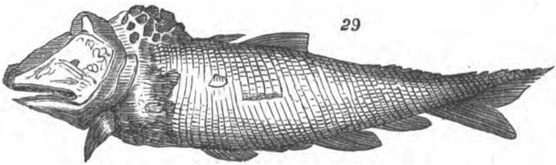
49. The fossils of the Permian strata approximate generally to those of Carboniferous times—their *facies* is decidedly Palæozoic. Most of the plants belong to genera which are abundant in the Carboniferous strata, and some species are said to be common to both formations. Some eighteen or twenty species of plants are known in the English Per-



28, Producta horrida.

* Here, as elsewhere throughout this treatise, the strata are described in *ascending* order.

mian rocks; among these are lepidodendra and calamites, but sigillaria and stigmaria have not yet been met with. Sponges and a few corals occur. Trilobites are entirely wanting, the crustaceans being poorly represented. Molluscs (fig. 28) are comparatively abundant; but the most important fossils are the fishes. These are chiefly ganoids (fig. 29), and all possess the 'heterocercal' or unequally



29, Palæoniscus comptus.

bilobate tail. It is noteworthy that this character distinguished the fishes of all the Palæozoic formations—from the Silurian up to the Permian. It is in the strata younger than the Permian that the 'homocercal' type, to which belong most existing species, first makes its appearance. Labyrinthodonts have been met with, and two species of *Protorosaurus*, a genus of reptiles. The foot-prints in the red sandstones of Dumfriesshire are also believed to be reptilian.

50. The physical conditions under which the Permian deposits of Britain were accumulated were partly marine, and partly, as Professor Ramsay maintains, lacustrine. In Lancashire and Scotland, according to him, large inland lakes existed, in which the lower red sandstones were laid down; and the foot-prints, worm-tracks, sun-cracks, rain-pittings, and ripplings so often met with in the strata, point, as he thinks, to shore surfaces, while the dwarfed and meagrely represented magnesian limestone fossils of the Lancashire district resemble the fauna of an inland sea like the Caspian. The magnesian limestone of the east of England, with its numerous and well-grown marine organisms, points, on the other hand, to free communication with open sea. It seems highly prob-

able, indeed, that nearly all Scotland, and the mountainous districts of England and Wales, together with considerable portions of Ireland, existed as part of a wide continental area in Permian times. Across this area, stretching into Germany, extended large inland lakes or seas, some of which had a more or less free communication with the ocean. The land was clothed with a vegetation strongly resembling that of Carboniferous times; but many of the old species and genera had become extinct, and new forms occupied their places. The shores of the lakes were haunted by amphibians and reptiles, and the opener seas teemed with an abundant fauna of molluscs, fishes, and other marine organisms. In Scotland and in Germany, many volcanoes existed, throwing out great quantities of stones and dust and ashes, and sheets of lava. The climate of the period may be inferred from the aspect of the fossils to have been mild and genial; but the presence of the coarse breccias, with their scratched stones and erratics, shews us that these mild climatic conditions were occasionally interrupted so as to allow of ice-rafts and icebergs in the latitude of Central England.

51. *General Character of Palæozoic Fauna and Flora.*—In summing up the general character of the Palæozoic fauna, we find that it was distinguished by the large number of what have been termed *synthetic* or *comprehensive* types—that is to say, types which, while belonging fundamentally to some particular division of the animal kingdom, yet present in their structure characteristics of one or more contemporaneous or as yet non-existing types. Among animals may be mentioned the labyrinthodonts, which were true amphibians, but possessed at the same time certain reptilian characteristics, and thus shadowed forth, as it were, a type which did not appear until later on in the world's history. The ganoid fishes are also examples of the same peculiarity, for besides being true fishes, they also partook of reptilian characteristics. Again, among the plants, similar facts have been noted; thus, the lepidodendroids, which were true acrogens, had yet the foliage of conifers.

52. The most prominent groups in Palæozoic times were graptolites, crinoids, and certain corals, brachiopods, trilobites, and ganoids. Graptolites and trilobites did not outlive the close of the Palæozoic age. Most of the cup-and-star corals belong to a type which is nearly restricted to the same age—there being only one or two examples of the Palæozoic type * met with in strata newer than the Permian. The brachiopods attained their greatest development in Palæozoic seas, as did also the crinoids—the former during Silurian and the latter in Carboniferous times. Among plants, cryptogams were the predominant forms, the lepidodendroids and sigillariæ being specially characteristic.

53. Many Palæozoic species were characterised by their large size as compared with species of the same groups that belong to later times. Thus, some trilobites and other crustaceans were larger than any modern species of crustaceans. The Palæozoic amphibians also much exceeded in size any living members of their class. Again, the modern club-mosses, which are insignificant plants, either trailing on the ground or never reaching more than two feet in height, were represented by great lepidodendroid trees.

54. Some living genera have come down from Palæozoic times. Among these are lowly organised protozoans and a number of molluscs, such as *Lingula*, *Crania*, *Terebratula*, *Ostrea*, *Avicula*, *Nucula*, *Chiton*, &c.

* The Palæozoic type of cup-and-star corals is distinguished by having the vertical plates, or *septa* (which spring from the inner surface of the wall of the coral), in multiples of four. The cup-and-star corals of Mesozoic, Cainozoic, and Post-tertiary seas belong, on the other hand, to a type which has its septa in multiples of six. This type, however, although chiefly developed in times later than Palæozoic, is also met with in Carboniferous and Devonian strata.

SECONDARY OR MESOZOIC FORMATIONS.

TRIASSIC* OR NEW RED SANDSTONE.

55. The Secondary or Mesozoic formations are separated from those of Palæozoic age by a great 'break in the succession'—a strongly marked and violent unconformability presents itself everywhere between the Triassic deposits and the older formations upon which they rest. The unconformability of the Permian upon the Carboniferous, although well marked, cannot be said to be violent; for, as a rule, the Permian strata have the same, or approximately the same, dip as the Carboniferous when the two formations occur together. But the Triassic strata bear no such relation to the formation immediately preceding them. All the Palæozoic strata had been upheaved, dislocated, metamorphosed, and extensively denuded before the Triassic deposits began to be laid down. These latter circle round the outskirts of the present high grounds of Wales and the north of England, and overlap the Permian and Carboniferous strata in such a way as to lead to the inference that the configuration of Wales and Northern and Central England in Triassic times had even then assumed much of its present appearance. Such a violent unconformability implies the lapse of long ages, during which the faunas and floras would necessarily undergo many modifications. Consequently, we might have anticipated that the fossils of the Triassic strata would differ greatly from those of Palæozoic rocks. They shew us, indeed, that most of the great Palæozoic types had become quite extinct, while many new

* The term *Triassic* has reference to the *threefold* grouping of this formation in Germany. In England, the Permian and Triassic strata used to be grouped together as 'New Red Sandstone'—a designation now restricted to the Triassic formation. Sometimes the formation is called the *Poikilitic* or *Pœcilitic*, from the Greek for *variegated*.

races had been ushered in, which kept their place down to the close of Mesozoic ages.

56. In England, the Triassic strata or Trias comprise two groups. The lower group (Bunter) is composed of red and mottled sandstones, and pebble-beds or uncompacted conglomerates; the upper group (Keuper) is separated from the lower by a calcareous or dolomitic conglomerate, and is made up of variously coloured sandstones, which are overlaid with thin sandstones and marls (waterstones), and the whole topped with a thousand feet of red marls (clays), containing beds of rock-salt and gypsum. The whole thickness of the Bunter and Keuper groups in England is over two thousand feet. The strata cover considerable areas, especially in Cheshire and South Lancashire, and the shires of Stafford, Warwick, Nottingham, Leicester, Lincoln, &c. Strata of the same age yield rock-salt and gypsum in the north of Ireland (Antrim and Londonderry). Certain yellow sandstones near Elgin in Scotland, formerly classed as 'Old Red,' have been assigned to the Trias, from the fact that they have yielded reptilian remains of a higher grade than one would expect to meet with in Old Red Sandstone strata; one of the Elgin fossils being *Hyperodapedon*, which has also been obtained from undoubtedly Triassic strata. This, however, cannot be considered conclusive as regards the age of the Elgin sandstones.

57. Immediately above the 'Keuper marls' come a set of dark shales, and gray and greenish marls, and gray limestones. These are called the Rhætic or Penarth beds. They are highly fossiliferous.

58. In Germany, the Trias is divided into three groups—namely, Bunter, Muschelkalk, and Keuper; the middle group, which is composed mostly of limestone, full of marine fossils, is wanting in Britain.

59. In the New Red Sandstone of Britain, fossils are seldom found—a characteristic of most red sandstone deposits; and such as do occur consist principally of plants, amphibian foot-prints and fishes. The Rhætic beds, however, contain numerous marine fossils; but these beds must be looked upon rather as intermediate between the Tri-

assic and Jurassic strata. At all events, they have been deposited under conditions differing widely from those which obtained during the accumulation of the true New Red Sandstone. Professor Ramsay is of opinion that the red colouring of strata is often due to the beds having been deposited in great inland seas; and he calls attention to the fact that such red strata are usually unfossiliferous, while they also frequently contain beds of rock-salt, gypsum, and magnesian limestone. These phenomena, he thinks, are only reconcilable with deposition in inland seas, where great evaporation and concentration are possible. Seas of this kind are not favourable to ordinary testaceous life (hence, in red sandstone deposits, the general absence of molluscs, crustaceans, &c.), while, on the other hand, their shores might well be haunted by amphibians. Rain-pittings and sun-cracks are of common occurrence also; and these appearances are likewise quite in keeping. For, along the margins of such inland seas, great evaporation would often expose wide reaches of muddy and sandy beach to atmospheric influences. Professor Ramsay is inclined to believe that, from the close of the Silurian period and the beginning of Old Red Sandstone times, down to the end of the New Red Sandstone period and the time when the Rhætic or Penarth beds began to be deposited, we have proofs of the prolonged existence of one or more great inland waters—a continuity of terrestrial conditions, in fact. In these waters, which may sometimes have been brackish—sometimes, also, have communicated with open ocean, and at other times have been fresh—the Old Red Sandstone (as distinguished from the Devonian strata), a great portion of the Carboniferous system, the Permian, the Trias, and the lower part of the Rhætic series, were successively deposited. The Devonian strata, the Carboniferous Limestone, the Magnesian Limestone in part, the Muschelkalk of Germany, and the upper part of the Rhætic beds, would represent the accumulations that gathered in the opener sea during that long succession of geological periods.

60. The foot-prints of *Labyrinthodon*, and teeth of the same genus of gigantic amphibia, are the most characteristic

fossils of the English New Red Sandstone. The same beds have also yielded spines and teeth of fishes, and four saurians—*Rhyncosaurus*, *Stagonolepis*, *Telerpeton*, and *Hyperodapedon*—the last named being closely allied to the living *Sphenodon* of New Zealand. In addition to these, we have also in British strata remains of two crocodilian reptiles—*Thecodontosaurus* and *Palæosaurus*. Here, likewise, we find the earliest traces of mammalia, which are represented by the teeth of a small marsupial animal called *Microlestes*. The genus labyrinthodon seems to have died out in Triassic times. The plants met with in British strata are referable chiefly to *Calamites*, *Equisitites*, and conifers. But the continental and North American strata of the same, or approximately the same age, have yielded plant-remains in great abundance. Cycads make their first appearance there, and are very numerously represented; ferns, *Calamites*, *Equisitites*, and conifers are also plentiful. Cryptogams are no longer, as in Palæozoic times, the predominant types.

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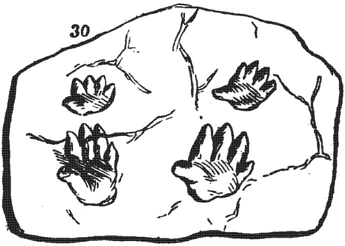


30, Labyrinthodon foot-prints.

61. In the Rhætic beds of Britain, we meet with a thin band of bone-breccia, which has long been noted for its remains of saurians and fishes. The same beds have likewise yielded a number of marine fossils, chiefly conchifers.

62. In Germany, we have, besides the brackish and fresh-water red sandstones and marls, with their few organic remains, considerable thicknesses of marine strata of Triassic age. These strata exhibit, in some districts, a remarkable intermingling of Palæozoic and Mesozoic genera of molluscs, thus shewing that the great break in succession between the Palæozoic and Mesozoic strata in Britain, which necessarily implies the lapse of long ages, yet was effected before the extinction of many well-known Palæozoic types of marine

life. The strata in which occurs this remarkable intermingling of forms are called the Hallstadt and St Cassian beds. The Muschelkalk of Germany contains numerous shells, amongst which the most characteristic are a genus of nautiloid shells, called *Ceratites*, and *Gervillia*—a shell closely resembling the *Aviculæ*. Lily-encrinites are also very abundant. Remains of several large saurians also occur. One of these (*Placodus*) was furnished with short flat palatal teeth, which enabled it to crush the shell-fish on which it fed.

63. The North American Trias is remarkable for bipedal impressions, which are nearly all trifid, and are believed to be the foot-prints of gigantic birds—four times as large as the living ostrich. Ganoid fish-remains occur, and the jaws of a small insectivorous mammal have been met with. Plant-remains are so numerous as in Virginia to form seams of excellent coal, one of which attains a thickness of thirty or forty feet.

64. The general aspect of the Triassic fossils indicates warm conditions of climate, and this genial climate seems to have extended to arctic regions, for Trias with characteristic fossils occurs in Spitzbergen.

JURASSIC OR OOLITIC.*

65. The Oolitic strata of Britain are abundantly developed in England, covering a large area in Yorkshire between the mouth of the Tees and Filey Bay, and extending south from the river Humber along the western borders of the great flats of Lincoln and Cambridge, from which they sweep south-west in a broad belt across the midland counties to the Bristol Channel and the shores of the English Channel between Lyme Regis and Durlestone Head. Strata of this age are only sparingly shewn in Scotland, occurring in mere patches in some of the Western Islands, and near Brora on the east coast of Sutherland. In Ireland, Oolitic strata are likewise very poorly developed, being visible only in some parts of Antrim.

* *Jurassic*, from the *Jura* Mountains, where rocks of this age are well developed. *Oolitic* (egg-stone), from the structure of many limestones of this age in Britain, which are composed of grains like the roe of a fish.

66. The formation consists of the following series :

	Feet.
4. Portland or Upper Oolites	920
3. Oxford or Middle Oolites	850
2. Bath or Lower Oolites	1450
1. The Lias	1200

67. The Lias is composed chiefly of laminated clay, with thin alternating beds of blue or gray earthy limestone. Here and there, however, the beds are somewhat arenaceous —this is specially the case about the middle of the series, where ironstones also are not uncommon. The Cleveland ironstones are of this age. The top of the Lias is capped with sand. The Lias yields numerous remains of reptiles, fishes, molluscs, and corals.

68. The Lower Oolites include the following groups, in ascending order :

a. The Inferior Oolite : a series of arenaceous limestones and calcareous freestones.

b. The Fuller's Earth : chiefly blue and yellow clays, shales and marls.

c. Great or Bath Oolite : a series of calcareous oolitic sandstones, sandy flags, and blue limestones, which are sometimes very flaggy, and locally called 'slates,' but towards the top of the series the limestones are white and thick-bedded.

d. The Cornbrash and Forest Marble : a series of clays, sands, and limestones, some of which are oolitic, others mere masses of shells. In Yorkshire this series contains seams of ironstone and coal.

69. The Oxford or Middle Oolites comprise two groups :

e. The Oxford Clay : a dark gray or blue clay, containing here and there in its lower portions some calcareous sandstone.

f. The Coralline Oolite : a mass of various limestones, some of which are highly oolitic, others made up of corals irregularly aggregated (Coral Rag), and yet others fine-grained and crystalline. This calcareous set of beds is underlaid and overlaid by sandstones and grits, which are often calcareous.

70. The Upper or Portland Oolites consist of three groups, which in ascending order are as follows:

g. The Kimmeridge clay: generally a shaly clay, with occasional bands of calcareous grit or ferruginous oolite. Sometimes it becomes highly carbonaceous, approaching to the character of an imperfect shaly coal.

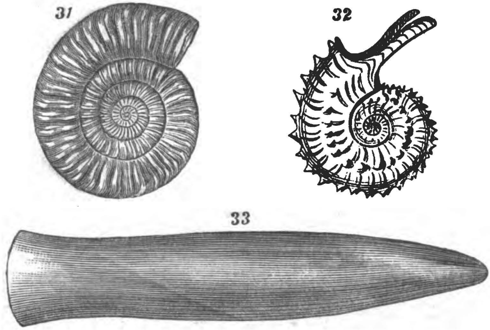
h. The Portland Beds: a series of sands and sandstones passing up into calcareous grit and limestone.

i. The Purbeck Beds: distinguished from all the preceding groups and sub-groups in being mostly of fresh-water origin. They contain also traces of old land-surfaces, consisting of vegetable soil (dirt-beds) with the roots and stems of fossil plants.

71. Jurassic rocks are well developed on the Continent. They enter largely into the composition of the Jura Mountains. Jurassic strata occur also in Germany (as in Würtemberg, Bavaria, Westphalia), and in France. They are met with in North America, as among the eastern ridges of the Rocky Mountains, in the Sierra Nevada, in the Arctic regions, and elsewhere. Rocks of the same age have been detected in many places along the Andes. In India and Australia they are also known.

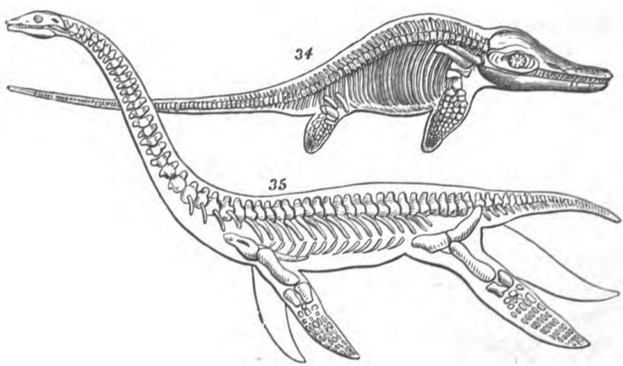
72. The Jurassic strata are as a rule highly fossiliferous. The land-plants consist mainly of ferns, conifers, and cycads, resembling in this respect the Trias. The lower classes of the animal kingdom are abundantly represented by foraminifers and sponges, by a great variety of corals, by crinoids (both fixed and free forms), by star-fishes, echinoids, &c. The molluscs present many forms which are not known in Palæozoic rock—the last of two characteristic Palæozoic families, *Spirifer* and *Leptæna*, dying out in the Lias. Among lamellibranchs, *Gryphæa* and other genera of oyster-shaped shells are perhaps most abundant. But by far the most characteristic molluscs of Jurassic times are the cephalopods—*Ammonites* (figs. 31, 32) and *Belemnites* (fig. 33). Ammonites appear first in Triassic strata, but they attained an extraordinary development in the Jurassic seas. The shell is chambered—the septa or partitions of the chambers being highly folded along the margin.

More than three hundred species of ammonites are known —although the genus is now quite extinct. *Belemnite* is the internal shell or bone of another group of cephalopods (dibranchs), represented in modern seas by the



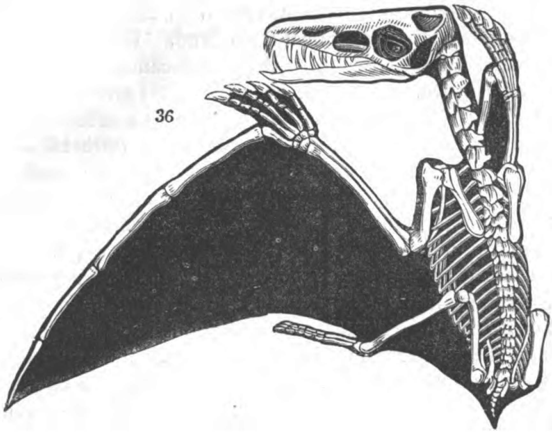
31, Ammonites bisulcatus; 32, Ammonites Duncani; 33, Belemnites paxillosus.

cuttle-fish and the squid. The ancient cuttle-fishes must have swarmed in Jurassic waters, for some beds are actually crammed with their internal bones. The Arthropoda are represented by worms, crustaceans, true spiders, and insects (including beetles, butterflies, dragon-flies, &c.). Among fishes we find cestraciont and other sharks, rays, and ganoids, which last usually have homocercal tails. Reptiles flourished in great numbers during the Jurassic period. Chelonians or turtles, lacertilians or lizards, and crocodiles, are all represented. But the most characteristic reptiles were the huge sea-saurians, *Ichthyosaurus* (fig. 34), *Plesiosaurus* (fig. 35), and *Pliosaurus*. Of ichthyosaurs, upwards of thirty species have been detected. They were very large reptiles, sometimes attaining a length of forty feet. The head was long, and furnished with conical, striated teeth, and the eyes were of extraordinary size. They were provided with paddles resembling somewhat those of the whale. The plesiosaur, of which also there were many species, had a long tapering snake-like neck supporting a relatively small head. The body was short, and furnished with comparatively longer paddles than the ichthyosaur. One species was not less than twenty-five feet in length. The pliosaur was allied to the plesiosaurs; it had, however, a short neck, which



34, Ichthyosaurus communis; 35, Plesiosaurus dolichodeirus.

supported an enormous head. *Cetiosaurus* was another huge reptile, reaching a length of sixty or seventy feet, and standing probably some ten feet high. Unlike the three preceding reptiles, the cetiosaurus was terrestrial, or frequented marshes and river-sides. It seems to have been a vegetable feeder. The numerous *coprolites*, or fossil droppings of ichthyosaur, prove that animal to have been carnivorous, as were also plesiosaurus and pliosaurus. Beside these and other forms there existed in Jurassic times winged reptiles. Among these the most characteristic was *Pterodactylus* (fig. 36). This animal attained no great size (a foot or so, the spread of the wings being some three feet). Most of the bones were hollow like those of birds, but the skin, teeth, and claws were reptilian. The outer finger of the forearm was greatly elongated, and between this long finger, the side of the body, and the hind limb, stretched the membranous wing. In the lithographic stone of Solenhofen in Bavaria, which is of the age of the Coral Rag, are found the remains of a bird (*Archæopteryx*) differing from all other birds, living or extinct. It had two free claws belonging to the wing, and a lizard-like tail longer than the body, composed of separate vertebræ, each of which supported a pair of quill feathers. The bird was about the size of a rook, was probably a vegetable feeder, and perched on trees. The fresh-water beds of Purbeck,



36, Pterodactylus crassirostris.

and also the Stonesfield Slate (Great Oolite), have yielded mammalian remains, chiefly jaws and a few detached bones. The animals which these represent were all small, and were most probably marsupials — some of them feeding on insects, and others on vegetables.

73. During the Jurassic period the area now occupied in Britain and Ireland by the older rocks appears to have been for the most part dry land, but all to the east of that area was sea, which extended over considerable regions in Europe. In this sea were numerous coral reefs—now forming limestones. The neighbouring lands were abundantly clothed with cycads, ferns, and conifers. Chambered shells and cuttle-fishes were so extraordinarily abundant that they may be said to be specially characteristic of the period.

Another most marked feature in the life of that age was the huge marine reptiles which were wonderfully numerous during Liassic times. The Oolitic or Jurassic strata, looked at broadly, consist of successive alternations of clay deposits and calcareous accumulations, which point to oscillations of the earth's crust, and to deflection of currents. The coral reefs could only have increased in clear water—that is, of course, at a distance from land. When by some movement of the earth's crust the sea became shallow, then mud and silt were swept out over the coral groves, and the corals died. By and by, however, owing to subsidence of the crust, the sea deepens; the shore-line retreats, as it were; silt and mud cease to be thrown down; and the corals again appear, and reefs are built up so as eventually to form another limestone. And this interchange of conditions continued during all the Jurassic period, in some places being more marked than in others. It is not necessary to infer, however, that every such alternation of clay and calcareous beds indicates oscillations of the crust. A change in the direction of the ocean currents might often cause silt to be deposited now in one place, now in another; and such deflections might sometimes be induced by the silting up of the sea or by the denudation of land. Sometimes the land in Jurassic times was partly submerged, and its prostrate forests became buried and preserved in the same way as those of Carboniferous times. But from the fact that so few ancient land-surfaces of the period have been thus preserved, we may conclude that the Jurassic lands remained for the most part above the old sea-level, and were thus subjected to the action of the atmospheric agents of denudation, and completely despoiled. The climate appears to have been warm, and from the fact that Jurassic fossils (ammonites and belemnites) have been obtained from arctic regions, it is clear that climatic conditions must have been remarkably uniform over the whole hemisphere. Yet it must be noted that in Scotland, near Brora, we have evidence of the former action of ice, in a coarse boulder conglomerate with erratics, intercalated among Oolitic strata.

CRETACEOUS OR CHALK.*

74. The Cretaceous or Chalk formation is composed of two series—upper and lower; the former being exclusively marine, and the latter partly marine and partly of fresh-water origin. The Jurassic strata in England are flanked along their eastern borders by a great belt of Cretaceous strata, underneath which they dip. These strata form the Yorkshire Wolds, cover large areas in Norfolk and Suffolk and Hertford; compose the Chiltern Hills, Salisbury Plain, the North and South Downs, and occupy the south part of the Isle of Wight.

75. The Lower Cretaceous series contains two groups—the Wealden and the Lower Greensand. The lowest of these—the Wealden—consists of a great series of sands, clays, shales, and sandstones, 1500 or 1600 feet in thickness. It is subdivided into the Weald Clay and the Hastings Sand—the latter being the undermost. The beds are nearly all of fresh-water origin, and resemble the deposits laid down at the mouth of some great river. They occupy the district known as the Weald of Kent, Surrey, and Sussex—whence the name *Wealden*. The fossils consist mostly of fresh-water mussels, river snails, cyprides, and fishes. Land-plants also occur, and numerous gigantic reptiles.

76. The Lower Greensand consists of irregular alternations of clays and sands, some of which are highly calcareous, and others ferruginous. Sometimes silicate of iron gives a greenish tinge to the beds, but the commonest colour is dark brown or red. The Lower Greensand is quite conformable with the Wealden, but it is entirely of marine origin.

77. The Upper Cretaceous series comprises six groups, which are here given in descending order:

	Feet.
f. Maestricht and Faxoë beds	100
e. White Chalk with flints	up to 1000 or more.
d. White Chalk without flints	600
c. Chalk Marl	100
b. Upper Greensand	up to 150
a. Gault	200

* *Creta*, chalk.

78. The Gault forming the basement group of the series, reposes unconformably upon the Lower Greensand, when that is present; but often the Upper Cretaceous beds lie upon pre-Cretaceous rocks—namely, Jurassic, Triassic, and even Palæozoic strata. The Gault is a tough, blue clay. It is characterised by the abundance of peculiar forms of cephalopods, and is exclusively marine.

79. The Upper Greensand consists principally of sands and clays; sometimes the sands are hardened into sandstone. Here and there they are also calcareous. Green-coloured beds are not common, despite the name of the deposit. The group contains, near Farnham in Surrey, a band of phosphatic nodules and concretions, probably of coprolitic origin in part. The Upper Greensand is of very variable thickness, not more than nine inches in some places. It is probably a shore deposit. Its fossils are chiefly marine, but reptilian remains are sometimes wonderfully numerous, and the bones of two species of birds have been met with.

80. The Chalk Marl is an argillaceous limestone, lying quite conformably upon the preceding group. It passes upwards quite conformably into the next group.

81. The White Chalk without flints is a thick-bedded mass of a soft, pure, white limestone or chalk, which shades gradually up into the overlying strata. The Chalk with flints differs lithologically from the underlying Chalk, simply in containing rows of nodules and tabular sheets of black flint. Here and there, small pebbles are found in the Chalk, but they are very rare. Near Croydon, a large boulder of granite, apparently of Scandinavian origin, occurred. Its fossils prove the Chalk to have been exclusively marine, and, for the most part, a deep-sea accumulation.

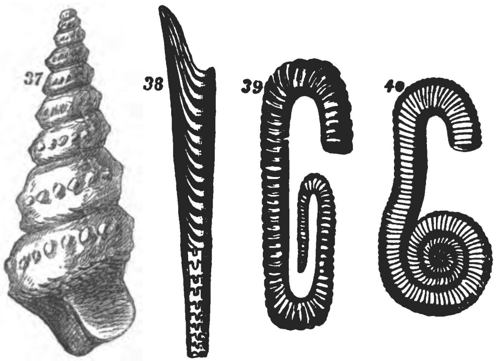
82. The Maestricht and Faxoë beds are not known in Britain. They consist chiefly of loose yellowish limestone, made up almost entirely of fossils. They are seen near Maestricht in Holland, and at Faxoë in the island of Seeland (Denmark). A white pisolitic limestone, resting in hollows of the chalk in the north of France, has also been assigned to this group. The Maestricht beds contain an intermingling of Cretaceous and Tertiary fossils.

83. Cretaceous rocks are met with in Belgium, France, Spain, Italy, Greece, Switzerland (where the Lower Cretaceous are called *Neocomian*), Savoy, Westphalia, Saxony, Northern Germany, Moravia, Bohemia, Poland, Russia, &c. They also occur in British North America, east of the Rocky Mountains, where they contain good coals. They are seen at various localities in the United States; in South America, along the Andes and on the Pacific coast; in Australia; in India; and even in North Greenland, where some of the fossil leaves are of the same species as are met with in European Cretaceous rocks.

84. As the Cretaceous rocks of Britain are mostly of marine origin—many of them indicating deep-sea conditions—we need feel no surprise that land-plants are of uncommon occurrence in British Cretaceous strata. In the Lower Cretaceous strata, they consist principally of ferns, cycads, and conifers; in the more purely marine upper series, plants are rarely met with in Britain, but we know from the evidence supplied by strata of the same age, near Aix-la-Chapelle, that the land then supported an abundant flora, among which were numerous ferns, some of them tree-ferns, conifers—the most common of which greatly resembles *Sequoia* or *Wellingtonia*—screw pines, and araucarians like those of Australia. But the most remarkable forms belong to the dicotyledonous angiosperms—that class which includes all plants that have a bark—excepting conifers. These forms consist of species of oak, bog-myrtle, walnut, fig, and a number of proteaceous plants, some of which are referred to living genera, chiefly belonging to Australia. A similar admixture of modern forms is met with among the Cretaceous flora of America.

85. The protozoa were very abundantly developed in Cretaceous times, chalk being composed in large measure of the exuviæ of minute rhizopods. Sponges of many varied forms were also numerous. Corals are well represented. Among mollusca the polyzoa are exceedingly numerous. The brachiopoda are represented especially by *Terebratulæ*, which are often very abundant. Lamellibranchs or ordinary bivalves are numerous, and some of

them are exceedingly characteristic of the Cretaceous deposits. The extinct genus *Inoceramus* is one of these. Univalves are not abundant, and seldom occur in the White Chalk. But the most characteristic molluscs were the cephalopods. Ammonites of many and various forms abounded—such as *Crioceras* (a ram's horn); *Ancycloceras* (elbow horn); *Hamites* (*hamus*, a hook), fig. 39; *Toxoceras* (*toxon*, a bow); *Baculites* (*baculum*, a stick), fig. 38, &c. All these resembled more or less uncoiled ammonites; *Turrilites*



37, Turrilites; 38, Baculites; 39, Hamites; 40, Scaphites.

(fig. 37) was a whorled or turreted spiral. The echinoderms are also very numerously represented, especially by the sea-urchins. The crustacea are not particularly noteworthy—the most abundant forms being fresh-water ostracoda (*Cypris*), which are common in the Wealden beds. Among fishes we find ganoids, and representatives of the shark families—cestracionts, hybodonts, and selachians. Teleost fishes (which comprise most of the living genera) make their first appearance in Cretaceous strata. The Cretaceous species were related to modern types—salmons, perch, herring, &c. The reptiles consisted of ichthyosaurs, plesiosaurs, pterodactyles, &c. In the Wealden deposits the most characteristic form is the *Iguanodon*—an herbivorous reptile, about sixty feet in length. It had short fore-limbs, and is believed to have walked upon its hind-legs. Another reptile, apparently peculiar to Cretaceous times, was the *Mososaurus*, which may have been some twenty-four feet in length; it was marine. The birds are represented by two small swimmers, allied to gulls. In American Cretaceous strata, bird-remains are not quite so rare.

86. *Physical and Climatic Conditions.*—During the deposition of the Cretaceous strata, a very large part of Central and Southern Europe was submerged. The period began in England by the formation of the Wealden—the delta of a great river that probably flowed from the west, and entered the Cretaceous sea which at that early period seems to have covered wide regions in Western and Central Europe. The land which this river drained was clothed with ferns, cycads, and conifers, and haunted by huge dinosaurians, like cetiosaurus and iguanodon. Turtles and crocodiles frequented the waters, which also abounded with ganoids and sharks. After some time depression ensued, the river delta was overflowed by the sea, and the shores of the Cretaceous land retreated, so that eventually a deep ocean overspread a large part of the European area—extending from the north of Ireland, at least, to the Crimea, and from the south of Sweden to the south of Bordeaux. But this ancient ocean was not of uniform depth, for islands seem to have existed here and there, and the shore-line appears to have been very irregular. The waters of the sea swarmed with life, more especially with the minute foraminifera, whose shells gradually gave rise to a white and gray calcareous accumulation or *chalk*. This deposit probably took place only in deep water, at a distance of some miles from the shore, which would account for the general absence of earthy ingredients and land-plants, &c. The abundance of sponges in the white chalk also speaks to the same conclusion. Other microscopic organisms furnished the silica which was afterwards to appear as nodules, &c. of flint. Fishes abounded, chiefly ganoids, but sharks were not uncommon; and horny-scaled fish like salmon, herring, and perch, were also present. But the most abundant and remarkable forms were the cephalopodous molluscs. These

literally swarmed. Echinoderms were likewise exceedingly abundant. We know little of the flora that covered the land after the depression of the Wealden area. But after a long series of ages had elapsed, after all the lower Cretaceous deposits had been laid down, and the upper Cretaceous strata were being accumulated, we know that a great change in the flora had come about. Dicotyledonous angiosperms —which comprise all native European trees except conifers—had appeared. It may aid the student's conception of the geographical changes which have taken place since Cretaceous times, when he learns that the greater part of the Alps are composed of Cretaceous strata, and therefore that the now highest mountains of Europe had then no existence. The Pyrenees are likewise younger than this period, as are the Himalaya also. The greatest stretch of land in Europe during Cretaceous times was in the north—the Ural Mountains, the Scandinavian Mountains, and the higher grounds of the British Islands, forming then the most elevated tracts in the European area. The climate of the Cretaceous period, as far as one can judge from the fossils, was warm and sub-tropical, and this temperature must have extended up to at least 12° of the pole, for characteristic plants of the Cretaceous period have been obtained in Greenland (lat. 71° N.) and Spitzbergen (lat. 78° N.), consisting of ferns and cycads. The oleander occurs among these. At the same time we have evidence to prove that icebergs or ice-floes occasionally floated in the Cretaceous sea, and dropped erratics over the sea-bottom.

87. *General Character of Mesozoic Fauna and Flora.*— The corals consist almost exclusively of the modern type. Echinoids and star-fishes abounded, but crinoids and echinoderms, so common in Palæozoic times, were now not so numerous. Among molluscs, brachiopods were no longer the dominant forms. The gasteropods and lamellibranchs comprised a number of genera which are represented in modern seas. But the most characteristic molluscs of Mesozoic times were the cephalopods: in this great class, the sub-kingdom of the mollusca reached its culmination.

Some of the higher grades of the crustacea, unknown in Palæozoic strata, appeared in Mesozoic times, and the same was the case with insects. Among fishes, ganoids and elasmobranchii (shark tribes of hybodonts and cestracionts) were the dominant forms, but teleostean fishes were not uncommon. Many of the ganoids now possessed homocercal tails. The labyrinthodonts died out in Triassic times. But the reigning vertebrates of Mesozoic times were the reptiles—all the species and nearly all the genera becoming extinct before the Tertiary age. There were swimming reptiles (*Ichthyosaurus*, *Plesiosaurus*, &c.), snake-like reptiles (*Mososaurus*), herbivorous reptiles (*Cetiosaurus*, *Iguanodon*, &c.), and flying reptiles (*Pterodactylus*). The Mesozoic age is thus often termed the Age of Reptiles. Birds make their first appearance in Mesozoic strata—some of them shewing reptilian characteristics. Modern types, however, appear in the younger Mesozoic formations. The oldest known mammal belongs to Triassic times: it was of small size and marsupial, as perhaps were all the other mammalia found in Mesozoic formations. The flora of Mesozoic times consisted principally of conifers, tree-ferns, and cycads, the last reaching then their greatest development. Towards the close of the period, angiosperms and palms flourished.

TERTIARY OR CAINOZOIC FORMATIONS.

EOCENE.*

88. The oldest formation of the Tertiary or Cainozoic division, as developed in England, chiefly occurs in two districts, called respectively the Hampshire and London basins. It seems at one time to have stretched continuously from the coast of Suffolk across the whole south-east part of England down to the coast of Dorset. But owing to subsequent subterranean action, accompanied and followed by

* From *eos*, dawn, and *kainos*, recent. The molluscan species in this formation are nearly all extinct; the modern species which occur shew the *dawn of recent* life.

great denudation, it has disappeared entirely from that wide tract that stretches west from Hampshire through the Weald to the English Channel and the Strait of Dover. The formation comprises three groups—upper, middle, and lower—the united thickness of which reaches more than 2500 feet.

89. The Lower Eocene rests apparently conformably upon the chalk, and consists principally of sands (Thanet Sands), a variable set of sands and clays above these (Woolwich and Reading series), and the London Clay, forming the uppermost section of the group. These beds are nearly all of marine origin, but traces of fresh-water conditions occur in the Woolwich and Reading series.

90. The Middle Eocene contains three series: namely, (1) The Bagshot series—chiefly sands and clays, all marine; (2) The Headon series—clays, sands, and limestone, partly marine and partly fresh-water; (3) The Osborne series—sandstone, limestone, and sands, fresh and brackish water.

91. The Upper Eocene contains: (1) The Bembridge series, consisting of limestone, oyster-bed, and mottled clays and marls—fluvio-marine; (2) The Hampstead series, consisting chiefly of clays and marls; mainly of fresh-water origin, a few of the highest beds only being marine.

92. Nearly all the fossils met with in the Eocene are of extinct species, nevertheless a glance at these organic remains suffices to shew that the fauna and flora of the period resembled generally existing animals and plants. But if we wish to find the nearest analogues or representatives of European Eocene life, we must seek for them in tropical and sub-tropical countries.

The Eocene formation is well represented in France and Belgium. Strata of the same age also occur in Austria (Vienna basin), Malta, Corsica, Greece, Crete, Cerigo, Southern Spain and Portugal, the Azores, North Africa, and North America along the borders of the Atlantic, the Mexican Gulf, and the Pacific, and also in the Rocky Mountain regions.

93. Among the protozoa the most remarkable forms are the shells of *Nummulites* (fig. 41), which were so abundant as

to give rise to limestones of extraordinary thickness. Nummulitic limestones occur in the Swiss Alps several thousand feet in thickness. The same rock enters largely into the composition of the Pyrenees, the Carpathians, and the Himalaya. In Egypt it was quarried for the building of the Pyramids. Among the mollusca the most abundant forms are gasteropods and lamellibranchs, belonging for the most part to living genera; but only a very small number, about three or four per cent., are of living species. The characteristic ammonites, &c. of Cretaceous times are not represented. Fishes abound, chiefly teleostean, but ganoids occur, and sharks and rays are common. Turtles, snakes, lizards, and crocodiles were the reptiles of Eocene times. Birds are not uncommon, all the existing orders being represented. Mammals are numerous, and represent nearly all the existing orders. The most characteristic forms belong to the ungulata. Of these the *Palæotherium* (fig. 42) was an herbivorous pachyderm, the largest species being about the size of a horse, and resembling the living tapir in the form of the head and in its short proboscis. The *Anoplotherium* was more slender

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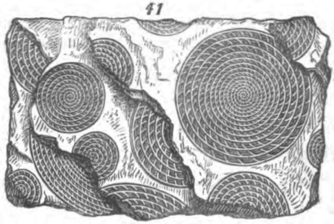
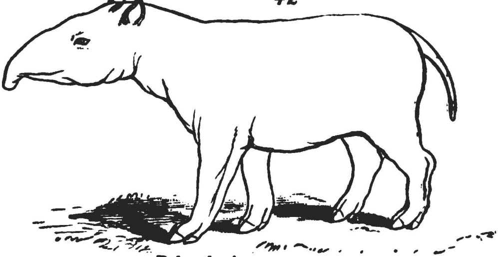


41, Nummulites.

42



42, Palæotherium magnum.

and elegant in its form, and partook of characteristics between the pachyderms and ruminants; some of the anoplotheres being, as Cuvier inferred, light, graceful, and agile as the gazelle. Most of the quadrupeds were herbivorous, but carnivora also occur, such as *Hyænodon*, the oldest known example of a carnivorous animal hitherto met with in British fossiliferous strata.

94. The land-plants of Eocene times consist principally of forms which are now restricted to tropical and subtropical regions. Among these are numerous remains of palms, various proteaceæ, fig, cinnamon, screw-pine, cucurbitaceous fruits, and fruits of various species of acacia, &c.

95. Although the Eocene strata rest apparently conformably upon the Chalk, yet there can be no doubt that a great lapse of time separates the accumulation of the two formations. Indeed, the lower member of the Eocene usually reposes upon a bed of rolled flints, which have evidently been derived from the denudation of the underlying Cretaceous strata. The White Chalk tells us of a deep sea, while the earliest Eocene deposits indicate deposition in a somewhat shallow sea, which overspread the south-east of England from Suffolk to Dorset, and extended into the Netherlands and the north of France. This sea received the waters of some large rivers, flowing from west and north-west in England, and from the south in France. The lands drained by these rivers seem to have enjoyed a warm climate, and to have been covered with a tropical vegetation—the fruits of palms often dropping into the water, and being floated in large numbers out to sea. Several kinds of birds and quadrupeds occupied the land, and the waters were haunted by turtles, sea-snakes, and crocodiles, of species, however, which are now all extinct. Towards the close of the Lower Eocene period, the sea became deeper, the shore-lines receded, and purely marine accumulations were formed over the surface of the fresh and brackish water deposits. Similar conditions ushered in the Middle Eocene—the lower portions of which are exclusively marine, but the higher beds (Osborne and Headon series) shew that the sea became partially silted up, and was rendered brackish by the great rivers which

continued to flow into the London and Hampshire districts. The sea in Middle Eocene times was still tenanted by forms of life now only met with in the tropics—by volutes and cowries, beautiful corals and polyzoa, besides many great sharks and rays. Where the waters were fresh or brackish,—that is, at and opposite the mouths of the large rivers—marine organisms did not flourish ; but in such places fresh-water shells were common, and with these, land-shells and plants were often associated, having been carried down to sea by the rivers. The Upper Eocene deposits were laid down under fluvio-marine conditions—some of the beds containing marine fossils, others fresh-water organisms, and yet others a brackish-water fauna. The character of the fossils indicates the continuance of warm climatic conditions—the land was covered with a kind of tropical vegetation, and supported a well-marked mammalian fauna, consisting of pachyderms chiefly, which may have been preyed upon by the hyænodon.

96. The Eocene formation of France indicates the former existence of a great bay of the sea in the neighbourhood of Paris. Into this sea flowed a large river or rivers, giving rise to beds of fresh-water or brackish-water strata, which alternate with marine accumulations, just as is the case in the English areas. Mammalian remains are very plentiful in the French Eocene—the 'Gypseous series of Montmartre' having yielded nearly fifty species of quadrupeds—chiefly pachyderms, such as palæotherium ; but carnivorous animals also occur, as hyænodon, a species of dog, and a weasel. Squirrels and bats existed then, and the marsupials were represented by an opossum—all these animals being of extinct species. Birds were numerous, as were also reptiles. Foot-prints are likewise very numerous and well marked, and indicate an abundant fauna. Of the marine divisions of French and foreign Eocene deposits, the most characteristic fossils are *Nummulites*. So abundant are these that their remains compose mountain-masses in some cases. Nummulitic limestone occurs at a height of 10,000 feet above the sea in Switzerland, and at an elevation of 16,500 feet in Western Tibet. The same formation has

been traced along the northern regions of Africa into Asia Minor, and across Persia to the mouths of the Indus. It is found also in many other places in Central Asia, and has been noticed as far east as Eastern Bengal and the frontiers of China. Thus, the student learns that some of the most marked features of the globe's surface are of comparatively modern date. For neither the Alps nor the Himalaya had any existence before Eocene times. At the time the nummulitic limestone was accumulating, the sea flowed over the sites of these mountain ranges, and over the areas where in subsequent ages the Pyrenees and the Carpathians made their appearance. In short, it becomes evident that, during the deposition of the Eocene strata, Europe existed as an archipelago—the sea then covering large areas which are now dry land. In the central Alps of Switzerland, some of the Eocene strata are so highly metamorphosed that they closely resemble some of the most ancient deposits of the globe, consisting as they do of crystalline rocks, marble, quartz-rock, mica-schist, and gneiss. The Eocene of Switzerland contains, in some places, immense ice-floated erratics.

MIOCENE.*

97. This formation is very sparingly developed in Britain. At Bovey Tracey, in Devonshire, it is represented by a patch of fresh-water strata not more than 300 feet thick, containing numerous plant-remains, which in some places form beds of lignite. The species consist of ferns, palm, vine, laurel, fig, oak, *Sequoia*, &c., and indicate a genial climate. In the island of Mull there occur great masses or sheets of basalt, interstratified with which are found thin layers of hardened clay, containing numerous impressions of leaves, and sometimes consisting almost entirely of a mass of compressed leaves. These leaves have the same character as those met with in true Miocene deposits in Switzerland and elsewhere. In some places beds of coal, quite like ordinary Carboniferous coal, occur among the basalts. The lignite of Antrim is also of this age.

* From *meion*, less, and *kainos*, recent. Living species of mollusca are in a *minority* among the fossils.

98. But it is from the Miocene deposits of other countries that our knowledge of this period is chiefly derived. In Auvergne, Cantal, and Velay, in France, a considerable area of fresh-water Miocene beds occurs. They indicate the former existence of great fresh-water lakes. Many mammalia occupied the surrounding land—among these were palæotheres, several species of *Cainotherium*—a genus allied to anoplotherium—the carnivorous hyænodon, some opossums, &c., and with these were associated crocodiles, tortoises, snakes, &c. Towards the close of the Miocene period volcanoes commenced to throw out lava and ashes in Central France. In other parts of France (as in Touraine), marine Miocene strata occur which are of more recent date than the lacustrine beds just referred to. The shells and other fossils in these marine strata indicate a warm climate. Among the shells some twenty-five per cent. belong to recent species. Miocene deposits are also well developed in Belgium, Germany, Austria, and Northern Italy; but those of Switzerland are perhaps the most remarkable. They consist of fresh-water and marine deposits called 'Molasse,' in three groups—lower, middle, and upper. The Molasse forms mountain-masses lying between the Jura and the Alps—that is, in the region of the great lakes. The Lower Molasse is chiefly of fresh-water origin, consisting of old shingle beds several thousand feet in thickness, which form mountains, as the Righi, near Lucerne. When these beds began to be laid down, the sea prevailed over a large part of Switzerland. Into this sea flowed several rivers, cumbering the sea-bottom with their deltas. The adjoining land was covered at this time with a tropical vegetation, shewing, among other plants, various palms, as date-palms, fan-palms, &c., numerous ferns, species of cinnamon, and some forms allied to modern American species, as a cypress, and a tulip-tree. The Lower Molasse was deposited during a slow movement of depression, and the filling-up of the sea-bottom seems for a long time to have kept pace with the subsidence. At length, however, this movement exceeded the rate of deposition, and so the sea prevailed, and marine deposits,

forming the Middle Molasse, were laid down over the Lower Molasse, or fresh-water beds. The Middle Molasse contains a number of shells and other fossils, which are also met with in the French Miocene (Faluns of Touraine), and in beds of the same age at Vienna. They indicate warm climatic conditions, and some plant-remains shew that a tropical vegetation still characterised the adjacent lands. The Upper Molasse is fresh-water, and shews that the rivers again prevailed over the sea, and that lacustrine conditions succeeded to marine. The vegetation of the land differed somewhat from that of the Lower Molasse period—many of the old species having apparently died out, while new ones occupied their place. But the general character of the flora still indicates warm climatic conditions. There grew in Switzerland at this time a most luxuriant vegetation, embracing many forms now only met with in warm latitudes; such as palms, cinnamon trees, &c., along with which were associated many species of maple, plane-trees, cypresses, sarsaparilla, &c. Altogether, nearly 500 species of plants have been found in the Upper Molasse, and more than 800 insects. The same strata have yielded a mastodon, a fox, and other mammals, salamanders, tortoises, reptiles, and fishes.

99. Miocene deposits occur in Greenland, Iceland, Spitzbergen, and at other places within the Arctic Circle. These beds contain a similar assemblage of plant-remains; the palm-trees, however, being wanting. It is certainly wonderful that within so recent a period as the Miocene, a climate existed within the arctic regions so mild and genial as to nourish there beeches, oaks, planes, poplars, walnuts, limes, magnolias, hazel, holly, blackthorn, logwood, hawthorn, ivy, vines, and many evergreens, besides numerous conifers, among which was the *Sequoia*, allied to the gigantic *Wellingtonia* of California. This ancient vegetation has been traced up to within eleven degrees of the pole, and there can be no doubt that the trees actually grew where they are found, for their roots are got penetrating the ancient soil.

100. It is remarkable that some of the Miocene deposits

of Northern Italy contain huge erratics of alpine rocks, which could only have been dropped into their present position by the action of floating ice.

101. Among the mammalia that inhabited Europe in Miocene times may be mentioned the proboscidians, dinotherium and mastodon; rhinoceros, hippopotamus, giraffe, antelope and various deer, monkeys; carnivorous animals, such as hyænodon, machairodus, &c., besides the palæotheres and other herbivorous and marsupial animals referred to above.

102. During the Miocene period, large volcanoes existed in the region of the Western Islands of Scotland and the north of Ireland. The rocks forming the island of Staffa and the Giants' Causeway were erupted at this time. Volcanoes also existed in France.

PLIOCENE.*

103. This formation is meagrely represented in Britain by the so-called 'Crag' deposits of Suffolk and Norfolk—the united thickness of which does not exceed one hundred feet. The beds are classified as follows:

Newer Pliocene................	3. Norwich Crag.
Older Pliocene..............	2. Red Crag.
	1. Coralline Crag.

104. The Coralline Crag consists chiefly of soft marly sands, with here and there thin flaggy limestones. It is exclusively marine, thirty-one per cent. of its fossil mollusca belonging to extinct species.

105. The Red Crag consists of sand and gravel, with rolled shells. It rests here and there in hollows of the Coralline Crag, but as a rule the two deposits lie side by side. Twenty-five per cent. of its molluscous remains belong to extinct species.

106. The Norwich Crag is a fluvio-marine accumulation of sand, gravel, and loam. It contains marine shells,

* From *pleion*, more, and *kainos*, recent. Living species are in a *plurality* among the mollusca.

together with land and fresh-water shells, and the bones of mammalia. Of the marine molluscs eighteen per cent. are extinct. All, or nearly all, the land and fresh-water shells are of living species.

107. The marine fossils of the British Older Pliocene indicate a colder climate than prevailed in Europe during Miocene times, for northern shells predominate. These are more common in the Red Crag than in the Coralline Crag, but they are still associated with some types that are now restricted to more southern latitudes. In the Newer Pliocene, the shells indicate a still cooler condition of climate, most of them being of temperate and cold-temperate species.

108. The mammalia that inhabited Britain during Pliocene times are typically represented by species of elephant, mastodon, and rhinoceros.

109. The most noted deposits of Pliocene age in the continent of Europe occur in Sicily and Italy. In the former they rise to a height of three thousand feet above the sea, and extend over nearly half the country. The sub-Apennines consist, in their upper portions, of strata belonging to the same formation. Other well-known examples are found in the neighbourhood of Antwerp. All these mentioned are of marine origin. The Aralo-Caspian formation (Pliocene), which occurs round the coasts of the Caspian, Aral, and Black Seas, is partly of marine and partly of fresh-water formation. In South Carolina (North America), beds supposed to be of the same age have yielded an abundant mammalian fauna, including camels, a rhinoceros, a mastodon, an elephant, several species of horse, a deer, a wolf, a fox, a tiger as large as that of Bengal, &c.

110. Before the accumulation of the Pliocene, Britain had probably assumed a continental condition; some portion, indeed (as in Suffolk and Norfolk), was submerged, but there may have been, and most probably was, a connection with the continent. The evidence shews that during the period there was great depression in the Mediterranean area. The climate would appear at first to have been mild and genial in Britain; but the marine fossils indicate a

gradually decreasing temperature. There is even evidence of floating ice in British seas at this time; and the presence of certain British shells in the Italian Pliocene beds seems to shew that the Mediterranean Sea also shared in the same decrease of temperature.

III. *General Character of Cainozoic Fauna and Flora.*—The fauna and flora of the Tertiary age evince a gradual approach to those of our own day. The vegetation of Eocene times shews that England was clothed with palms like those of the Moluccas. The flora also embraced a number of plants closely resembling Indian and Australian forms. In Miocene times, the vegetation was not quite so tropical, the predominating plants being like living North American types. In the Pliocene, the European flora closely approximated to the present. Among animals, the lowly foraminifera played an important part, giving rise to massive nummulitic limestones. The number of extinct species of invertebrate animals becomes less and less as we pass from Eocene to Miocene and Pliocene deposits. In the Eocene, only from three to five per cent. of the molluscs are of living species; the proportion increases in the Miocene from seventeen to twenty-five per cent.; while in the Pliocene, it reaches from thirty-five to ninety or ninety-five per cent. The teleosts or common osseous fishes abounded, and sharks were common; but the ganoids were evidently declining. Reptiles were represented by several species of crocodiles and turtle, and snakes also occurred. Birds were numerous, and their remains are common in the French Tertiaries. In Miocene times, France had species of parrot, trogon, swallow, secretary bird, adjutants, cranes, flamingoes, ibises, pelicans, &c. A species of vulture and a kingfisher occur in the English Eocene. Among mammals, the most characteristic forms of early Tertiary times were the palæotheres and anoplotheres, associated with which were various carnivores, rodents, marsupials, &c. In Miocene times, the mammalia are represented chiefly by elephants, mastodons, and dinotheres; but contemporaneous with these we find also palæotheres, and other tapir-like brutes. In the Pliocene age, mastodons, elephants, rhinoceroses, hippopotami, and the sabre-toothed machairodus, &c. were the prevalent mammalian forms.

POST-TERTIARY OR QUATERNARY FORMATIONS.

PLEISTOCENE* AND PALÆOLITHIC.

112. The deposits belonging to this formation consist of marine, fresh-water, and glacial or ice deposits. They occur very abundantly in the British Islands, and afford striking evidence to shew that the lowering of temperature which marked the deposition of the Pliocene was continued until Britain became subjected to quite an arctic climate. The succession of events in this country will be best followed by describing briefly the various deposits in ascending order.

113. *Preglacial Beds.*—These are typically represented by the Cromer Forest-bed of the Norfolk coast. This consists of the remains of an old forest—the roots of the decayed trees occurring in the ancient soil below. The tree-stumps are overlaid with lignite, clay, &c., containing fresh-water shells and the bones of some twenty terrestrial mammalia, among which are species of bear, elephant, rhinoceros, hippopotamus; Irish elk, musk-ox, beaver, &c. Many of the species are extinct, but some of them still survive in Europe. The whole is overlaid with a thick mass of a glacial deposit called *Till* or *Boulder-clay*.

114. *Stony Clay.*—This is generally an amorphous, unstratified, more or less tough and tenacious clay, abundantly charged with irregular-shaped stones of various sizes, which are scattered pell-mell through the clay. The stones are usually more or less smoothed and polished, and covered with striæ or scratches. The rock-surface upon which the deposit rests is often well smoothed and striated. Sometimes, however, the strata are much broken and disturbed below the clay. Similar smoothed and striated rock-surfaces are of common occurrence in many parts of the British

* From *pleistos*, most, and *kainos*, recent.

Islands, especially in hilly and mountainous districts. These are believed to be due to the action of great confluent glaciers, underneath which the country was at one time buried to a depth of more than 3000 feet. Rocks which have been rounded into dome-shaped bosses and hummocks by ice, are called *roches moutonnées.* The stony clays are the débris which accumulated underneath, and was dragged along by the great glaciers. They are unfossiliferous as a rule, but in maritime regions they sometimes contain marine shells of northern and arctic species. The shells are often crushed and broken. The stony clays are called *Till* or *Boulder-clay.* In Scotland, the Till contains, in some places, intercalated or interglacial beds of fresh-water origin, which have yielded remains of mammoth, Irish elk, reindeer, horse, and urus, or great extinct ox. Peat, also, and remains of oak, alder, and other plants, have been found in the same position. Here and there, especially in maritime districts, the Till has likewise yielded intercalated beds of marine origin, containing shells of northern and arctic species. These marine shell-beds are most abundantly developed in the Clyde basin; but they occur at many other places round the Scotch coasts. They are not always covered with Till. In England, especially in Lancashire and in the old district of East Anglia, marine deposits of sand, gravel, &c., containing shells which indicate temperate conditions of climate, occur intercalated between upper and under masses of stony clay; and the same phenomena are met with in Ireland. The highest level at which these shelly deposits have been met with is in North Wales, at a height of 1390 feet above the sea.

115. *Perched Blocks and Erratics.*—These are large angular blocks which are found resting on hill-tops and hill-slopes, and sometimes on the low grounds. They have usually travelled some distance from the rocks of which they once formed a part, and have evidently been stranded in their present positions by the glaciers when these were melting away.

116. *Kames or Eskers, and Ledges.*—These are long ridges, mounds, and conical heaps, or undulating accumu-

lations and terraces of gravel and sand. The deposits evidently have been formed by the waters that escaped from the melting glaciers when the climate was becoming ameliorated. The ledges mark the sites of ancient glacial lakes formed by the damming up of lateral valleys by the main glaciers. The Parallel Roads of Glenroy, in Lochaber, are a good example.

117. *Valley Moraines.*—These are heaps of angular earthy débris lying in mountain valleys. They mark the final stage in the disappearance of the glaciers.

118. All the deposits now mentioned are collectively termed glacial deposits, and the period of their deposition is spoken of as the Glacial period or Ice age. The grand lessons which they teach are these: (1) The cold of the glacial period came gradually on until it reached a climax, when the lowest masses of till were formed; at this time Scotland, Ireland, and the major portion of England were enveloped in one great ice-sheet; (2) This intense arctic condition of things was interrupted more than once by intercalated mild periods, when the ice melted away, and the land was clothed with vegetation, and occupied by a well-marked mammalian fauna; (3) During the accumulation of the glacial deposits, there were one or more periods of submergence; (4) The last stage of the period was a cold one, which passed gradually away.

119. *Cave and River Deposits of England.*—In the limestone caves of England have been found numerous remains of mammals, which are now either locally or wholly extinct. The remains lie upon the floors of the caves, enveloped in a kind of earth, mingled with which are fragments of limestone, &c., and they are often covered over with a pavement of stalagmite. Sometimes there are two or more pavements of stalagmite and layers of cave-earth and breccia. Rude flint implements, needles made of bone, &c., are found along with the animal remains, and thus shew that man was contemporaneous with the extinct mammalia. In the south-east of England, ancient river-gravels occur at a great height above the present river-valleys, and in these gravels are found similar mammalian remains and relics of man. The

evidence shews that since the extinct mammalia, and the men who made the flint implements, lived in South Britain, the river-valleys have been excavated to depths varying from twenty to a hundred feet.

120. The mammalia comprise a number of animals which could not have occupied the country at the same time; for some indicate an arctic or northern climate, such as the glutton, the reindeer, the musk-sheep, &c.; others again are temperate species, such as the bison, the urus, the Irish deer, &c.; while yet others are species which are now only met with in southern regions, such as the elephant, the hippopotamus, the rhinoceros, &c. Some hold that this indicates a period of strongly contrasted summers and winters, during which great *annual* migrations of the fauna took place; others maintain that the phenomena point rather to oscillations of climate, and that the migrations were *secular*. The latter view appears to be the more reasonable. It is most probable, indeed, that the cave-deposits and ancient river-gravels of England, with mammalian remains and flint implements, are of interglacial and preglacial age.

121. It may be mentioned here that archæologists have divided prehistoric times into three ages: (1) The Stone Age; (2) The Bronze Age; (3) The Iron Age. The Stone age is again subdivided into the Palæolithic or Old-stone age and the Neolithic or New-stone age. The Palæolithic age belongs to the Pleistocene, and the Neolithic, Bronze, and Iron ages, as we shall presently see, to the Recent period.

122. During the Pleistocene period, Britain had assumed much of its present configuration, but there were several considerable oscillations of level—our islands being sometimes united to themselves and the continent. It was a period of great alternations of cold and warm climatic conditions. The men who then occupied Britain were a savage race, who used rudely chipped flint implements, and were contemporaneous with many mammalian animals, some of which are now not found in Britain or temperate latitudes, while others are confined at present to arctic and southern latitudes, and yet others are wholly extinct. Similar climatic conditions are known to have obtained in

various regions in our hemisphere during this period. Scandinavia, like Britain, was invested with an ice-sheet which filled up the Baltic, and extended into Northern Germany. The Swiss and other glaciers of Europe greatly exceeded in size their present puny successors. All North America was covered with ice down to the latitude of New York. But in Sweden, Switzerland, Carinthia, Piedmont, Lombardy, and North America there are interglacial deposits, which point to great fluctuations of climate like those which obtained in Britain during the so-called Glacial period; the Swiss interglacial deposits have recently yielded relics of man.

123. *Changes of Climate.*—The most reasonable explanation of these great climatic changes is that given by Mr Croll's theory. Such an alternation of climates would come about during a period of great eccentricity of the earth's orbit. Glacial conditions would then supervene in that hemisphere whose winter happened in aphelion, while in the opposite hemisphere a mild climate would extend up to polar regions. The precession of the equinoxes, by changing the incidence of the seasons, would revolutionise the climate over both hemispheres, causing the ice to melt gradually away from the one hemisphere, and cold conditions to supervene gradually upon the other, and thus in course of time what had been the warm hemisphere would become the cold one, and *vice versâ.* Such alternations of climate would occur every 10,000 or 11,000 years, so long as a period of great eccentricity lasted. The last period of eccentricity to which the Ice age is believed to have been due, began upwards of 200,000 years ago, and lasted for 160,000 years.

124. It has been pointed out in previous paragraphs that a warm climate has been experienced by arctic regions at many different periods in the world's history, while indications of ice-action have been met with in several of the old formations, not only in this country, but in Central Europe, and in North America. If it be true that our great Glacial period was caused by eccentricity of the orbit, combined with precession of the equinox, it might have been

expected that the rock formations in Greenland, Spitzbergen, and other arctic regions, would afford indications that warm and genial climates have characterised such latitudes during various epochs in the past—for periods of great eccentricity must have often occurred since the earliest geological formation was deposited. And so in like manner we might have expected to find in the old formations of Britain and other temperate latitudes some proof of ice action. One of the most remarkable examples of the kind are the glacial deposits of the Miocene in the north of Italy, and those of the Eocene in Switzerland. It is difficult to believe that large icebergs could have been floating about in Italy at a time when a luxuriant vegetation was flourishing within twelve degrees of the pole. But it is quite easy to explain the anomaly on Mr Croll's theory; for the erratics of the Italian Miocene would simply indicate one of the cold periods, while the arctic Miocene flora would in like manner point to one or more of the warm periods comprised in the great Miocene age.

NEOLITHIC AND RECENT.

125. In the Pleistocene deposits, while all the invertebrates belong to living species, many of the mammalian animals are now extinct. In Recent deposits all the fossils are of species still living. The deposits are very heterogeneous, and consist of marine, fresh-water, and organic accumulations.

126. *Peat-mosses.*—These are extensive accumulations of vegetable matter, composed chiefly of the bog-moss. They often overlie prostrate forests. They are not always confined to the land, for in some places they occur at, and even below the sea-level. Similar appearances are noticed along the opposite coasts of the continent. They indicate a former much greater breadth of land—when probably no German Ocean existed. There are peat-mosses belonging to Neolithic, Bronze, and Iron ages.

127. *Raised Beaches.*—These are accumulations of silt, sand, and gravel, occurring in the form of ledges or terraces, or wide flats, at various places along our coasts.

They occur at different levels, and some of the higher ones possibly belong to the Glacial period. The lower level beaches have yielded relics of man, such as canoes and stone implements. These relics belong to the Neolithic age.

128. *Alluvia.*—These deposits are fresh-water, and often occupy the sites of old lakes. Canoes, &c. have been met with in these, associated in some cases with the remains of ox, pig, deer, sheep, &c.; shell-marl is also common in some alluvial deposits. The same assemblage of animals is met with occasionally in river alluvia. In Scotland, Ireland, north of England, and Wales, all the alluvium that forms terraces in the present river-valleys belongs to the Recent period, and has yielded remains characteristic of Neolithic times. In the south of England the river alluvium at high levels is of Pleistocene age, and contains Palæolithic implements, &c.; while the low-level gravels and alluvia belong to the Recent period, and contain remains of the Neolithic, Bronze, and Iron ages.

129. Along our coasts occur ridges and hummocks of blown sand, and banks of shingle, some of which are still being added to by the action of winds and waves.

130. The succession of changes after the melting of the great glaciers appears to have been as follows: (1) A continental condition, when Britain was joined to the rest of Europe. The men who came to our country after the close of the Ice age used polished stone implements, and were associated with the mammalian fauna which is still indigenous to our country. At this time Britain was covered with forests, and the bed of the German Ocean probably existed as an undulating plain clothed with woods. (2) A gradual submergence of the land resulting in the insulation of Britain, and a change of climate from something like that of Germany to a truly insular one. The decay of the ancient forests in hilly and maritime regions, and their envelopment in peat-mosses, dates from this time. (3) A partial re-elevation of the land, and the consequent retreat of the sea to its present position. It is quite possible that small glaciers may have existed in some of our mountain-valleys far on into the Neolithic and Recent period.

QUESTIONS.

Section 1. Give some account of what is meant by *geological structure.*

2. How is the frequent occurrence of blanks in the geological record explained?

3. What is the general testimony of geology as to the succession of life?

4. How has the fact, that the faunas and floras of the past depart more and more from those of the present, the farther we go back, been explained?

5. What is a *formation?*

6. What kinds of animals have the greatest vertical range?

7. Are widely separated areas of strata which contain the same assemblages of fossils necessarily contemporaneous? What is meant by the term *contemporaneous?* What is *homotaxis?*

8. What may be inferred from *conformability?* In the case of unconformability, what appearance do the fossils present along the line of junction? What does this teach us?

9. What is meant by 'a break in the succession?' What may be inferred from such a break?

10. How are former climatic conditions deduced from fossils? When all the fossil species are extinct, how do we reason from them as to former climatic conditions?

11. How are conditions of deposition deduced from fossils?

12. What are the commonest kinds of fossils?

13. What is meant by continuity in geological history?

14. Name the formations in order, beginning with the oldest.

15. Where do Laurentian strata occur in Britain? What is the oldest fossil believed to have been?

16. In what parts of the British Islands is the Cambrian developed? Name a characteristic fossil.

17. What is the general character of the Cambrian fossils?

18. How does the Silurian formation lie with regard to the Cambrian?

19. What great unconformity occurs in the Silurian? How is it marked? Of what age is the Bala limestone?—the Wenlock limestone?—the Mayhill sandstone?

20. In what localities in Britain are Silurian strata chiefly developed?

21. What are the most abundant Silurian fossils? Name a Silurian cephalopod. What were *Trilobites?* What were the most abundant of Silurian echinoderms?

22. What is the character of Silurian plants?

23. What may be inferred from fossils as to the climate of Silurian times?

24. What traces have we of Silurian volcanoes in Britain and Ireland?

25. What is the general character of Devonian fossils?

26. What is the character of the strata which occur in Wales, Scotland, and Ireland, on the same horizon as the Devonian?

27. Mention the chief points of difference between the Old Red Sandstone of Northern Scotland and that of the region south of the Grampians.

28. What relation does the Old Red Sandstone bear to the Carboniferous and Silurian formations in Scotland and Ireland? Mention the principal kinds of Old Red Sandstone fossils.

29. Under what physical conditions were the Old Red Sandstone and Devonian strata accumulated?

30. What has been inferred as to the climate of Devonian times? What indications of volcanic action are met with in rocks of this age?

31. Mention the groups of the Carboniferous formation.

32. What is the character of the lower group in Scotland?

33. In what respects does the Carboniferous limestone series of Scotland differ from that of England?

34. What is the character of the Millstone Grit?

35. Which group is the chief repository of coal in England? In what groups in Scotland do coals occur?

36. Which groups of the Carboniferous formation yield contemporaneous volcanic rocks?

37. What is the character of the coal that occurs in the contorted and disturbed part of the Appalachian coal-field?

38. Name three characteristic Carboniferous molluscs. What characteristic Silurian type died out in Carboniferous times? What was the *Labyrinthodon?* What was the *Rhizodus?*

39. To what division do most Carboniferous fossil plants belong?

40. What were *Calamites?—Lepidodendra?—Lepidostrobi?—Sigillariæ?—Stigmariæ?*

41. What is the origin of common coal, splint-coal, and gas-coal?

42. Give some account of the physical conditions of the British area during the deposition of the Lower Limestone Shale and Calciferous Sandstone series.

43. What were the conditions under which the Carboniferous Limestone series was deposited in Scotland and England?

44. What was the origin of the Millstone Grit series?

45. Under what conditions were the Coal-measures accumulated?

46. What movement of the earth's crust may be inferred to have taken place during the formation of the Coal-measures?

47. What do we know of the climate of Carboniferous times?

48. What is remarkable about the breccias of the Lower Permian? What are the German divisions of the Permian?

49. What relation do the plants of the Permian bear to those of the Carboniferous formation? What are the most important Permian fossils?

50. What appear to have been the physical and climatic conditions under which the Permian strata were deposited?

51. What is meant by a synthetic or comprehensive type?

52. Name some of the most prominent groups of Palæozoic times.

53. What was one distinguishing feature of many Palæozoic species?

54. Name some Palæozoic genera of molluscs which have survived to the present day.

55. What relation does the Triassic formation bear to the Palæozoic strata?

56. What minerals of importance do the Triassic strata yield?

57. What is the position of the Rhætic or Penarth beds?

58. What are the German subdivisions of the Trias?

59. How has the generally unfossiliferous character of red sandstone strata been accounted for? What is Professor Ramsay's view of the physical conditions under which the New Red Sandstone and Old Red Sandstone have been deposited?

60. What are the most characteristic fossils of the New Red Sandstone? What was *Microlestes*, and what is remarkable about it? What are the chief plants found in British Triassic strata?

61. What is notable about the Rhætic beds in Britain?

62. What is remarkable about the Hallstadt and St Cassian beds?

63. What are the most noteworthy fossils met with in the North American Trias?

64. What can we say as to the climate of Triassic times?

65. In what districts are Jurassic rocks chiefly developed?

66. Name the groups of the Jurassic formation.

67. In which group do the Cleveland Ironstones occur? What are the principal organic remains found in the Lias?

68. In which group do the Cornbrash and Forest Marble occur? What is this series in Yorkshire noted for?

69. What is the geological position of the Oxford clay? What is the general character of the Coralline Oolite?

70. Name the members of the Upper or Portland Oolites. What is the character of the Purbeck beds?

71. What European mountains are largely composed of Jurassic strata?

72. What are the chief kinds of Jurassic land-plants? What characteristic Palæozoic families of molluscs died out in the Lias? What was *Gryphæa?* What are the most characteristic molluscs of the Jurassic formation? What is a *Belemnite?* Name and describe shortly two sea-saurians. What are the Purbeck beds and the Stonesfield slate famous for?

73. What were the general physical and climatic conditions under which the Jurassic strata were deposited?

74. What is the general character of the Upper and Lower Cretaceous series?

75. What is the Weald clay? What are its chief fossils?

76. To what mineral is the green colour of certain Greensand strata due?

77. Name the groups of the Upper Cretaceous series in ascending order.

78. What is the Gault? What are its characteristic fossils? Whether is it marine or fresh-water?

79. What kind of deposit is the Upper Greensand?

80. What is the Chalk Marl?

81. What is the difference between the upper and lower groups of White Chalk? What is noteworthy of the chalk near Croydon?

82. What are the Maestricht and Faxoë beds? What is remarkable about the fossils of the Maestricht beds?

83. What are *Neocomian* strata?

84. What kinds of land-plants occur in British Cretaceous rocks? What remarkable plants have been found in the Cretaceous strata near Aix-la-Chapelle?

85. Of what is chalk largely composed? Mention some commonly occurring Cretaceous fossils other than molluscs and vertebrates. What was *Inoceramus?* Name some characteristic cephalopods. What minute crustaceans are common in the Wealden? What type of fish makes its first appearance in Cretaceous strata? Name some of the reptiles of the Cretaceous period. Describe *Iguanodon.* What was *Mososaurus?*

86. What were the physical and climatic conditions under which the Cretaceous strata were deposited?

87. What were the most characteristic molluscs of Mesozoic ages? What is noteworthy of Mesozoic ganoids? What large classes of vertebrates make their first appearance in Mesozoic times? What was the general character of Mesozoic floras?

88. What do we call the two chief areas of British Eocene strata?

89. Name the groups that compose the Lower Eocene.

90. Name the groups of the Middle Eocene, and say which are marine and which fresh-water.

91. Name the groups of the Upper Eocene, and say what is their origin.

92. What is most noteworthy of the Eocene fauna and flora?

93. What are *Nummulites?* What were the Eocene reptiles? What were *Palæotherium* and *Anoplotherium?*

94. What is the general character of the Eocene flora?

95. What were the general physical and climatic conditions under which the Eocene was deposited?

96. What is noteworthy of the gypseous series of Montmartre? What great mountains are known not to have been in existence before Eocene times, and how is this ascertained?

97. Of what age are the beds at Bovey Tracey, in Devonshire? What is the nature of the fossils found there? What is noteworthy of the basalt-rocks of Mull and Antrim?

98. Mention some of the distinguishing features of the Miocene beds of Auvergne, Cantal, and Velay in France. Describe shortly the conditions, physical and climatic, under which the Swiss Molasse was accumulated.

99. How far north have Miocene strata been traced?

100. For what is the Italian Miocene remarkable?

101. Name some of the mammals that lived in Europe during Miocene times.

102. Mention where some volcanoes existed in Miocene times.

103. Name the groups of the British Pliocene.

104. How many per cent. of extinct species of molluscs occur in the Coralline Crag?

105. What is the upper group of the Older Pliocene called?

106. What is the Norwich Crag? What are its fossils?

107. What kind of climate do the marine fossils of the Pliocene indicate?

108. What were the chief mammals that lived in Britain in Pliocene times?

109. Name some foreign equivalents of the English Pliocene.

110. What were the geographical and climatic conditions of the Pliocene period in Europe?

111. What are the percentages of living species of molluscs in the Eocene, Miocene, and Pliocene respectively?

112. What is the nature of the Pleistocene deposits of Britain?

113. What is the Cromer Forest-bed?

114. Describe the deposit called *till* or *boulder-clay*. What are *roches moutonnées?* What is *till?* What are interglacial beds?

115. What are *perched blocks* and *erratics?*

116. What are *kames* or *eskers*, and *ledges?*

117. What are *valley moraines?*

118. What are the grand lessons taught by the glacial deposits of the Pleistocene?

119. What is noteworthy of the cave deposits of England? What do the Palæolithic gravels of the south-east of England teach us?

120. What has been inferred as to climatic conditions from the mammalian remains of Pleistocene deposits?

121. What are the archæological subdivisions of prehistoric times?

122. What were the geographical and climatic conditions in Britain during Pleistocene times?

123. What is Mr Croll's theory of the cause of cosmical changes of climate?

124. What evidence in support of this theory is afforded by formations older than the Pleistocene?

125. What is peculiar about the fossils of recent deposits?

126. What are *peat-mosses?*

127. What are *raised beaches?* To what ages do they belong?

128. What are *alluvia?* To what ages do they belong?

129. What is *blown sand?*

130. What succession of changes followed in Britain after the melting of the great glaciers?

THE END.

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