X. Unconformability

Where one series of rocks, whether of aqueous or igneous origin, has been laid down continuously and without disturbance upon another series, they are said to be *conformable*. Thus in fig. 59 the sheets of rock numbered 1, 2, 3,

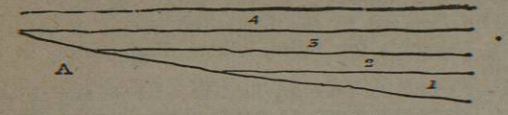

Fig. 59.—Overlap of conformable strata.

and 4 have succeeded each other in regular order, and exhibit a perfect conformability. They overlap each other, however, No. 2 extending beyond the edge of No. 1, No. 3 beyond that of No. 2, and so on. As already explained (p. 295), this structure points to a gradual subsidence and enlargement of the area of deposit. But all these conformable beds repose against the older platform A, with which they have no direct connexion. That platform may consist of horizontal or inclined strata, or contorted schist, or crystalline igneous rocks. In any case there is a complete break between it and the overlying rocks, which rest successively on different parts of the older mass. This relation is termed an unconformability. The upper conformable beds in fig. 59 are said to lie unconformably upon A.

It is evident that this structure may occur in ordinary stratified, or in igneous, or in metamorphic rocks, or between any two of these great series. It is most familiarly displayed among stratified masses, and can there be most satisfactorilv studied. The lines of bedding furnish a ready means of detecting differences of inclination and discordance of superposition. But even among igneous protrusions and in ancient metamorphic masses, distinct evidence of unconformability is not always difficult to trace.

Though conformable rocks may usually be presumed to have followed each other continuously without any great disturbance of geographical conditions, we cannot always be safe in such an inference. But an unconformability leaves no room to doubt that it marks a decided break in the continuity of deposit. Hence no kind of geological structure is of higher importance in the interpretation of the history of the stratified formations of a country. In rare cases an unconformability may occur between two horizontal groups of strata. In fig. 60, for instance, a set of beds C is shown

Fig. 60.—Unconformability among horizontal beds.

to lie conformably for some distance upon an older series *d*. Were nothing more to be seen than what appears towards the right hand, we might justifiably conclude the whole of the rocks to be conformable. By passing to the left, however, we should find evidence of the older group having been upraised and unequally denuded before the deposition of the newer. The denudation would show that the conformability was accidental, that the older rocks had really been upraised and worn down before the formation of the newer. In such a case the upheaval must have been so equable as not to disturb the horizontality of the lower rocks.

As a rule, however, it seldom happens that movements of this kind have taken place over an extensive area so equably as not to produce a want of conformability somewhere between the older and newer rocks. Most frequently the older formations have been disturbed, tilted at various angles, or even placed on end. They have likewise been irregularly and enormously worn down. Hence, instead of lying parallel, the younger beds run transgressively across the upturned denuded ends of the older. The greater the

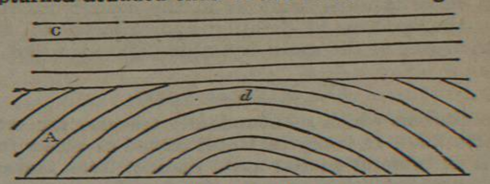

Fig. 61.—Section of unconformable rocks.

disturbance of the older rocks the more marked is the unconformability. In fig. 61, for instance, the series of beds A is uncomformably covered by the series C. At both sides of the arch the uncomformability is strongly marked, but at the centre *d* the two series seem to be conformable. An unconformability forms one of the great breaks in the geological record. In the foregoing figure, by way of illustration, we see at once that a notable hiatus in deposition, and therefore in geological chronology, must exist between series A and C. The older rocks had been deposited, folded, upheaved, and worn down before the accumulation of the newer series upon their denuded edges. These changes must have demanded a considerable lapse of time. Yet, looking merely at the structure in itself, we have evidently no means of fixing, even relatively, the length of interval marked by an unconformability. The mere violence of contrast between a set of vertical beds below and a horizontal group above it is no reliable criterion of the relative lapse of time between their deposition, for an older portion of a given formation might be tilted on end and be overlaid unconformably by a later part of the same formation. A set of flat rocks of high geological antiquity might, on the other hand, be covered by a formation of comparatively recent date, yet in spite of the want of discordance between the two, they might have been separated by a large portion of the total sum of geological time. It is by the evidence of organic remains that the relative importance of unconformabilities must be measured, as will be explained in part v.

Paramount though the effect of an unconformability may be in the geological structure of a country, it must nevertheless be in almost all cases local. The disturbance by which it was produced can have effected but a comparatively circumscribed region, beyond the limits of which the continuity of sedimentation may have been undisturbed. We may therefore always expect to be able to fill up the gaps in one district from the more complete geological formations of another. In fig. 61 we see that something is wanting between A and C. But in the structure of another country or a different part of the same country we might discover

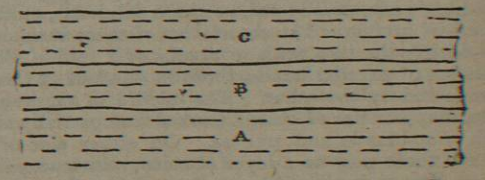

Fig. 62.—Section showing the groups of fig. 61 in conformable sequence, with the intervening blank (B) supplied.

the complete succession, as in fig. 62, where the whole of the rocks succeed each other conformably, and where the gap between A and C marked by the unconformability in fig. 61 is bridged over by the intermediate group of strata B.

PART V.—PALÆONTOLOGICAL GEOLOGY.

Palæontology is the science which treats of the structure, affinities, classification, and distribution in time of the forms of plant and animal life embedded in the rocks of the earth's crust. In one sense it may be regarded as a branch of zoology and of botany, its claim in this view to rank as a separate science resting almost solely on the fact that of the forms with which it deals but a small proportion belongs to the living world. In another aspect it may be looked upon as a branch of geology, seeing that its assistance is absolutely indispensable in many of the most familiar and fundamental problems of the latter science. It is under this last aspect that we have to regard it here. We shall consider merely those leading features of palæontological inquiry without some knowledge of which progress in modern geology would be impossible.

Fossils.—Palæontological geology, then, deals with the *fossils* or organic remains preserved in the rocks, and endeavours to gather from them information as to the history of the globe and its inhabitants. The term "fossil," meaning literally anything "dug up," was formerly applied indiscriminately to any mineral substance taken out of the earth's crust, whether organized or not. Ordinary minerals and rocks were thus included as fossils. For many years, however, the meaning of the word has been restricted, so as to include only the remains or traces of plants and animals preserved in any natural formation whether hard rock or superficial deposit. The idea of antiquity or relative date is not necessarily involved in this conception of the term. Thus the bones of a sheep buried under gravel and silt by a modern flood, and the obscure crystalline traces of a coral in ancient masses of limestone, are equally fossils.

Nor has the term fossil any limitation as to organic grade. It includes not merely the remains of organisms, but also whatever was directly connected with or produced by these organisms. Thus the resin which was exuded from trees of long-perished forests is as much a fossil as any portion of the stem, leaves, flowers, or fruit, and in some respects is even more valuable to the geologist than more determinable remains of its parent trees, because it has often preserved in admirable perfection the insects which flitted about in the woodlands. The burrows and trails of a worm preserved in sandstone and shale claim recognition as fossils, and indeed are commonly the only indications to be met with of the existence of annelide life among old geological formations. The droppings of fishes and reptiles, called coprolites, are excellent fossils, and tell their tale as to the presence of vertebrate life in ancient waters. The little agglutinated cases of the caddis-worm remain as fossils in formations from which perchance most other traces of life may have passed away. Nay, the very handiwork of man, when preserved in any natural manner, is entitled to rank among fossils; as where his flint-implements have been dropped into the prehistoric gravels of river-valleys, or where his canoes have been buried in the silt of lake-bottoms.

The term fossil, moreover, suffers no restriction as to the condition or state of preservation of any organism. In some rare instances the very flesh, skin, and hair of a mammal have been preserved for thousands of years, as in the case of the mammoths entombed within the frozen mud cliffs of Siberia. In most cases all or most of the original animal matter has disappeared, and the organism has been more or less completely mineralized or petrified. It often happens that the whole organism has decayed, and a mere cast in amorphous mineral matter, as sand, clay, ironstone, silica, or limestone remains; yet all these variations must be comprised in the comprehensive term fossil.

Conditions for the Preservation of Organic Remains.—At the outset the question naturally suggests itself how the remains of plants and animals come to have been preserved in rocks at all. If we observe what takes place at the present day, and argue that it may fairly be taken as an indication of what has been the ordinary condition of things in the geological past, we see that there must have been so many chances against the conservation of either animal or plant remains that their occurrence among stratified formations should be regarded as exceptional, and as the result of various fortunate accidents.

I. Consider, in the first place, what chances exist for the preservation of remains of the present fauna and flora of a country. The surface of the land may be densely clothed with forest, and abundantly peopled with animal life. But the trees die and moulder into soil. The animals, too, disappear, generation after generation, and leave no perceptible traces of their existence. If we were not aware from authentic records that central and northern Europe was covered with vast forests at the beginning of our era, how could we know this fact? What has become of the herds of wild oxen, the bears, wolves, and other denizens of primeval Europe? How could we prove from the examination of the surface soil of any country that those creatures had once abounded there? We might search in vain for any such superficial traces, and would learn by so doing that the law of nature is everywhere "dust to dust."

The conditions for the preservation of any relics of the plant and animal life of a terrestrial surface must therefore be always exceptional. They are supplied only where the organic remains can be protected from the air and superficial decay. Hence they may be observed in

1. *Lakes.*—Over the floor of a lake deposits of silt, peat, marl, &c., are formed. Into these the stems, branches, leaves, flowers, fruits, or seeds of plants from the neighbouring land may be carried, together with the bodies of land animals, insects, and birds. An occasional storm may blow the lighter debris of the woodlands into the water. Such portions of the wreck as did not float, and were not washed ashore again, might sink to the bottom. Of these the larger part would in most cases probably rot away, so that, in the end, only a very small fraction of the whole vegetable matter cast over the lake by the wind would be covered up and preserved at the bottom. In like manner the animal remains swept by winds or by river floods into the lake would run so many risks of dissolution that only a proportion of them, and probably merely a small proportion, would be preserved. When we consider these chances against the conservation of the vegetable and animal life of the land, we must admit that, at the best, lake-bottoms can contain but a meagre and imperfect representation of the abundant life of the adjacent hills and plains.

But lakes have a distinct flora and fauna of their own. Their aquatic plants may be entombed in the gathering deposits of the bottom. Their mollusks, of characteristic types, sometimes form, by the accumulation of their remains, sheets of soft calcareous marl, in which many of the undecayed shells are preserved. Their fishes, likewise distinctly lacustrine, no doubt must often be entombed in the silt or marl.

2. *Peat-mosses.*—Wild animals venturing on the more treacherous watery parts of a peat-bog are sometimes engulphed or "laired." The antiseptic qualities of the peat preserve such remains from decay. Hence from European peat-mosses numerous remains of deer and oxen have been exhumed. Evidently the larger beasts of the forest ought chiefly to be looked for in these localities.

3. *Deltas at River Mouths.*—From what has been said in previous pages (*ante*, pp. 276–8) regarding the geological operations of rivers, it is obvious that to some extent both the flora and the fauna of the land may be buried among the sand and silt of deltas. When we consider, however, that though occasional or frequent river-floods sweep dow,

trees, herbage, and the bodies of land animals, the remains so transported run every risk of decaying or being otherwise destroyed while still afloat, and that even if they reach the bottom they will tend to dissolution there unless speedily covered up and protected by fresh sediment, we must perceive that delta formations can scarcely be expected to give us more than a meagre outline of the varied terrestrial flora and fauna.

4. *Caverns.*—These are eminently adapted for the preservation of the higher forms of terrestrial life. Most of our knowledge of the prehistoric mammalian fauna of Europe is derived from what has been disinterred from *bone-caves.* As these recesses lie for the most part in limestone or in calcareous rock, their floors are commonly coated with stalagmite from the drip of the roof; and as this deposit is of great closeness and durability it has effectually preserved whatever it has covered or enveloped. The caves have in many instances served predatory beasts, like the hyæna, cave-lion, and cave-bear, as dens in which they slept, and into which some of them dragged their prey. In other cases they have been merely holes into which different animals crawled to die, or into which they fell or were swept by inundations. Under whatever circumstances the animals left their remains in these subterranean retreats, the result has been that the bones have been covered up and preserved. Still, we must admit that after all but a mere fraction even of the mammals of the time would enter the caves, and therefore that the evidence of the cavern-deposits, profoundly interesting and valuable as it is, presents us with merely a glimpse of one aspect of the life of the land.

II. In the next place, if we turn to the sea, we find certainly many more favourable conditions for the preservation of organic forms, but also many circumstances which operate against it. While the level of the land remains stationary, there can be but little effective entombment of marine organisms in littoral deposits; for only a limited accumulation of sediment will be formed until subsidence of the sea-floor takes place. In the trifling beds of sand or gravel thrown up on a stationary shore, only the harder and more durable forms of life, such as gasteropods and lamellibranchs, which can withstand the triturating effects of the beach waves, are likely to remain uneffaced.

Below tide-marks, along the margin of the land where sediment is gradually deposited, the conditions are favourable for the preservation of marine organisms. Sheets of sand and mud are there laid down. In those sediments the harder parts of many forms of life may be entombed and protected from decay. But only a small proportion of the total marine fauna may be expected to occur in such deposits. At the best, merely littoral and shallow-water forms will occur, and even under the most favourable conditions they will represent but a fraction of the whole assemblage of life in these juxta-terrestrial parts of the ocean. As we recede from the land the rate of deposition of sediment on the sea-floor must become feebler, until in the remote central abysses it reaches a hardly appreciable minimum. Except, therefore, where organic deposits, such as ooze, are forming in these more pelagic regions, the conditions must be on the whole unfavourable for the preservation of any adequate representation of the deep-sea fauna. Hard enduring objects, such as teeth and bones, may slowly accumulate and be protected by a coating of peroxide of manganese, or of some of the silicates above (p. 288) referred to as now forming here and there over the deep-sea-bottom. But such a deposit, if raised into land, would supply but a meagre picture of the life of the sea.

We must conclude therefore that of the whole sea-floor the area best adapted for preserving a varied suite of marine organic exuviæ is that belt which, running along the margin of the land, is ever receiving fresh layers of sediment transported by rivers and currents from the adjacent shores. The most favourable conditions for the accumulation of a thick mass of marine fossiliferous strata will arise when the area of deposit is undergoing a gradual subsidence. If the rate of depression and that of deposit were equal, or nearly so, the movement might proceed for a vast period without producing any great apparent change in marine geography, and even without seriously affecting the distribution of life over the sea-floor within the area of subsidence. Hundreds or thousands of feet of sedimentary strata might in this way be heaped up round the continents, containing a fragmentary series of organic remains belonging to those forms of shallow-water life which had hard parts capable of preservation.

There can be little doubt that such has in fact been the history of the main mass of stratified formations in the earth's crust. These piles of marine strata have unquestionably been laid down in comparatively shallow water within the area of deposit of terrestrial sediment. Their great depth seems only explicable by prolonged and repeated movements of subsidence, interrupted, however, as we know, by other movements of a contrary kind. These geographical changes affected at once the deposition of inorganic materials and the succession of organic forms. One series of strata is sometimes abruptly succeeded by another of a very different character, and we generally find a corresponding contrast between their respective organic contents.

It follows from these conclusions that representatives of the abyssal deposits of the central oceans are not likely to be met with among the geological formations of past times. Thanks to the great work done by the "Challenger" expedition, we now know what are the leading characters of these abyssal deposits of the present day. They have absolutely no analogy among the formations of the earth's crust. They differ, indeed, so entirely from any formation which geologists considered to be of deep-water origin as to indicate that, from early geological times, the present great areas of land and sea have remained on the whole where they are, and that the land consists mainly of strata formed at successive epochs of terrestrial debris laid down in the surrounding shallow sea.

Relative Value of Organic Remains as Fossils.—As the conditions for the preservation of organic remains exist more favourably under the sea than on land, marine organisms must be far more abundantly conserved than those of the land. This is true to-day, and has been true in all past geological time. Hence for the purposes of the geologist the fossil remains of marine forms of life far surpass all others in value. Among them there will necessarily be a gradation of importance regulated chiefly by their relative abundance. Now, of all the marine tribes which live within the juxta-terrestrial belt of sedimentation, unquestionably the *Mollusca* stand in the place of pre-eminence as regards their aptitude for becoming fossils. In the first place they almost all possess a hard durable shell, capable of resisting considerable abrasion, and readily passing into a mineralized condition. In the next place they are extremely abundant both as to individuals and genera. They occur on the shore within tide mark, and range thence down into the abysses. Moreover, they appear to have possessed those qualifications from early geological times. In the marine *Mollusca*, therefore, we have a common ground of comparison between the stratified formations of different periods. They have been styled the alphabet of palæontological inquiry. It will be seen, as we proceed, how much in the interpretation of geological history depends upon the testimony of sea-shells.

Looking at the organisms of the land, we perceive that as a rule the abundant terrestrial flora has a comparatively

small chance of being well represented in a fossil state, that indeed, as a rule, only that portion of it of which the leaves, twigs, flowers, and fruits are blown into lakes is likely to be partially preserved. Terrestrial plants, therefore, occur in comparative rarity among stratified rocks, and furnish in consequence only limited means of comparison between the formations of different ages and countries. Of land animals the vast majority perish and leave no permanent trace of their existence. Predatory and other forms whose remains may be looked for in caverns or peat-mosses, must occur more numerously in the fossil state than birds, and are correspondingly more valuable to the geologist for the comparison of different strata.

Relative Age of Fossils.—Although absolute dates cannot be fixed in geological chronology, it is not difficult to determine the relative age of different strata, and consequently of their enclosed organic remains. For this purpose the fundamental law is based on what is termed the "order of superposition." This law may be thus defined:—in a series of stratified formations the older must underlie the younger. It is not needful that we should actually see the one lying below the other. If a continuous conformable succession of strata dips steadily in one direction we know that the beds at the one end must underlie those at the other, because we can trace the whole succession of beds between them. Rare instances occur where strata have been so folded by great terrestrial disturbance that the younger are made to underlie the older. But this inversion can usually be made quite clear from other evidence. The true order of superposition is decisive of the relative ages of stratified rocks.

If therefore formations lie regularly above each other, B upon A, C upon B, D upon C, and so on, it is evident that the organic remains found in A must have lived and died before those in B were entombed; the latter must have been covered up before those in C, and these again before those in D. The chronological sequence of fossils must be determined first of all by the order of superposition of their enclosing strata. There is nothing in the fossils themselves, apart from experience, to fix their date. Unless, for example, we knew from observation or testimony that *Rhynchonella pleurodon* is a shell of the Carboniferous Limestone, and *Rhynchonella tetrahedra* is a shell of the Lias, we could not, from mere inspection of the fossils themselves, pronounce as to their real geological position. It is quite true that by practice a palæontologist has his eye so trained that he can make shrewd approximations to the actual horizon of fossils which he may never have seen before; but he can only do this by availing himself of a wide experience based upon the ascertained order of appearance of fossils as determined by the law of superposition. For geological purposes therefore, and indeed for all purposes of comparison between the faunas and floras of different periods, it is absolutely essential first of all to have the order of superposition of strata rigorously determined. Unless this is done the most fatal mistakes may be made in palæontological chronology. But when it has once been done in one typical district, the order thus established may be held as proved for a wide region where, from paucity of sections, or from geological disturbance, the true succession of formations cannot be satisfactorily determined.

Uses of Fossils in Geology.—There are two main purposes to which fossils may be put in geological research:—(1) to throw light upon former conditions of physical geography, such as the presence of land, rivers, lakes, and seas, in places where they do not now exist, changes of climate, and the former distribution of plants and animals; and (2) to furnish a guide in geological chronology whereby rocks may be classified according to relative date, and the facts of geological history may be arranged and interpreted as a connected record of the earth's progress.

1. A few examples will suffice to show the manifold assistance which fossils furnish to the geologist in the elucidation of ancient geography.

(*a.*) Former land-surfaces are revealed by the presence of tree-stumps in their positions of growth, with their roots branching freely in the underlying stratum, which, representing the ancient soil, often contains leaves, fruits, and other sylvan remains, together with traces of the bones of land animals, remains of insects, land-shells, &c. Ancient woodland surfaces of this kind are found between tide-marks, and even below low-water line, round different parts of the British coast. They unequivocally prove a subsidence of the land. Of more ancient date are the "dirt-beds" of Portland, which, by their layers of soil and tree-stumps, show that woodlands of cycads sprang up over an upraised sea-bottom and were buried beneath the silt of a river or lake. Still further back in geological history come the numerous coal-growths of the Carboniferous period, pointing to wide jungles of terrestrial or aquatic plants, like the modern mangrove swamps, which were submerged and covered with sand and silt.

(*b.*) The former existence of lakes can be satisfactorily proved from beds of marl or lacustrine limestone full of fresh-water shells, or from fine silt with leaves, fruits, and insect remains. Such deposits are abundantly forming at the present day, and they occur at various horizons among the geological formations of past times. The well-known nagelflue of Switzerland—a mass of conglomerate attaining a thickness of fully 6000 feet—can be shown from its fossil contents to be essentially a lacustrine formation.

(*c.*) Old sea-bottoms are vividly brought before us by beds of marine shells and other organisms. Layers of water-worn gravel and sand, with rolled shells of littoral and infra-littoral species, unmistakably mark the position of a former shore line. Deeper water is indicated by finer muddy sediment, with relics of the fauna which prevails beneath the reach of waves and ground-swell. Limestones full of corals, or made up of crinoids, point to the slow continuous growth and decay of generation after generation of organisms in clear sea-water.

(*d.*) Variations in the nature of the water or of the sea-bottom may sometimes be shown by changes in the size or shape of the organic remains. If, for example, the fossils in the central and lower parts of a limestone are large and well-formed, but in the upper layers become dwarfed and distorted, we may reasonably infer that the conditions for their continued existence at that locality must have been gradually impaired. The final complete cessation of these favourable conditions is shown by the replacement of the limestone by shale, indicative of the water having become muddy, and by the disappearance of the fossils, which had shown their sensitiveness to the change.

(*e.*) That the sea-floor represented by a fossiliferous stratum was not far from land is sufficiently proved by mere lithological characters, as has been already explained; but the conclusion may be further strengthened by the occurrence of leaves, stems, and other fragments of terrestrial vegetation which, if found in some numbers among marine organisms, would make it improbable that they had been drifted far from land.

(*f.*) The existence of different conditions of climate in former geological periods is satisfactorily demonstrated from the testimony of fossils. Thus an assemblage of the remains of palms, gourds, and melons, with bones of crocodiles, turtles, and sea-snakes, proves a sub-tropical climate to have prevailed over the south of England in the time of the older Tertiary formations. On the other hand, the presence of an intensely cold or arctic climate far south in Europe during post-Tertiary time can be shown from different kinds of evidence, such as the existence of the remains of arctic animals even as far as the south of England and of France.

This is a use of fossils, however, where great caution must be used. We cannot affirm that, because a certain species of a genus lives now in a warm part of the globe, every species of that genus must always have lived in similar circumstances. The well-known example of the mammoth and woolly rhinoceros having lived in the cold north, while their modern representatives inhabit some of the warmest regions of the globe, may be usefully remembered as a warning against any such conclusions. When, however, we find that not one fossil merely, but the whole assemblage of fossils in a formation has its modern analogue in a certain general condition of climate, we may at least tentatively infer that the same kind of climate prevailed where that assemblage of fossils lived. Such an inference would become more and more unsafe in proportion to the antiquity of the fossils and their divergence from existing forms.

2. When the order of superposition has been determined in a great series of stratified formations, it is found that the fossils at the bottom are not quite the same as those at the top of the series. As we trace the beds upward we discover that species after species of the lowest platforms disappears, until perhaps not one of them is found. With the cessation of these older species others make their entrance. These in turn are found to die out and to be replaced by newer forms. After patient examination of the rocks, it is ascertained that every well-marked formation is characterized by its own species or genera, or by a general assemblage or *facies* of organic forms. This can only, of course, be determined by actual practical experience over an area of some size. When the typical fossils of a formation are known, they serve to identify that formation in its progress across a country. Thus, as we trace the formation into tracts where it would be impossible to determine the true order of superposition, owing to the want of sections, or to the disturbed condition of the rocks, we can employ the fossils as a means of identification, and speak with confidence as to the succession of the rocks. We may even demonstrate that in some mountainous ground the beds have been turned completely upside down, if we can show that the fossils in what are now the uppermost strata ought properly to lie underneath those in the beds below them.

Observations made over a large part of the surface of the globe have enabled geologists to divide the stratified part of the earth's crust into systems, formations, and groups or series. These subdivisions are frequently marked off from each other by lithological characters. But mere lithological differences would afford at the best but a limited and local ground of separation. Two masses of sandstone, for example, having exactly the same general external and internal characters, might belong to very different geological periods. On the other hand, a series of limestones in one locality might be the exact chronological equivalent of a set of sandstones and conglomerates at another, and of a series of shales and clays at a third.

It is by their characteristic fossils that the divisions of the stratified rocks can be most satisfactorily made. Each formation being distinguished by its own assemblage of organic remains, it can be followed and recognized even amid the crumplings and dislocations of a disturbed region. The same general succession of organic types can be observed over a large part of the world, though, of course, with important modifications in different countries. This similarity of succession has been termed *homotaxis*—a term which expresses the fact that the order in which the leading types of organized existence have appeared upon the earth has been similar even in widely separated regions.

It is evident that in this way a method of comparison is furnished whereby the stratified formations of different parts of the earth's crust can be brought into relation with each other. We find, for example, that a certain series of strata is characterized in Britain by certain genera and species of corals, brachiopods, lamellibranchs, gasteropods, and cephalopods. A group of rocks in Bohemia, differing more or less from these in lithological aspect, contains on the whole the same genera, and many even of the same species. In Scandinavia a set of beds may be seen unlike, perhaps, in external characters to the British type, but yielding many of the same fossils. In Canada and many parts of the northern United States, other rocks enclose many of the same, and of closely allied genera and species. All these groups of strata are classed together as *homotaxial*, that is, as having been deposited during the same relative period in the general progress of life in each region.

It was at one time believed, and the belief is still far from extinct, that groups of strata characterized by this community or resemblance of organic remains were chronologically contemporaneous. But such an inference rests upon most insecure grounds. We may not be able to disprove the assertion that the strata were strictly coeval, but we have only to reflect on the present conditions of zoological and botanical distribution, and of modern sedimentation, to be assured that the assertion of contemporaneity is a mere assumption. Consider for a moment what would happen were the present surface of any portion of central or southern Europe to be submerged beneath the sea, covered by marine deposits, and then re-elevated into land. The river-terraces and lacustrine marls formed before the time of Julius Cæsar could not be distinguished by any fossil tests from those laid down in the days of Victoria, unless, indeed, traces of human implements were obtainable whereby the progress of civilization during 2000 years might be indicated. So far as regards the shells, bones, and plants preserved in the various formations, it would be absolutely impossible to discriminate their relative dates; they would be classed as "geologically contemporaneous," that is, as having been formed during the same period in the history of life in the European area; yet there might be a difference of 2000 years or more between many of them. Strict contemporaneity cannot be asserted of any strata merely on the ground of similarity or identity in fossils.

But the phrase "geologically contemporaneous" is too vague to have any chronological value except in a relative sense. To speak of two formations as in any sense contemporaneous which may have been separated by thousands of years seems rather a misuse of language, though the phraseology has now gained such a footing in geological literature as probably to be inexpugnable. If we turn again for suggestions to the existing distribution of life on the earth we learn that similarity or identity of species and genera holds good on the whole only for limited areas, and consequently, if applied to wide geographical regions, ought to be an argument for diversity rather than for similarity of age. If we suppose the British seas to be raised into dry land, so that the organic relics preserved in their sands and silts could be exhumed and examined, a general common facies or type would be found, though some species would be more abundant in or entirely confined to the north, while others would show a greater development in the opposite quarter. Still there would be such a similarity throughout the whole that no naturalist would hesitate to regard the organisms as those of one biological province, and belonging to the same great geological period. The region is so small, and its conditions of life so uniform and uninterrupted, that no marked distinction is possible between the forms of life in its different parts.

Widening the area of observation, we perceive that as we recede from any given point the forms of life gradually change. Vegetation alters its aspect from climate to climate, and with it come corresponding transformations in the character of insects, birds, and wild animals. A lake bottom would preserve one suite of organisms in England, but a very different group at the foot of the Himalaya Mountains, yet the deposits at the two places might be absolutely coeval, even as to months and days. Hence it becomes apparent that while strict contemporaneity cannot be predicated of deposits containing the same organic remains, it may actually be true of deposits in which they are quite distinct.

If, then, at the present time, community of organic forms obtains only in districts, regions, or provinces, it may have been more or less limited also in past time. Similarity or identity of fossils among formations geographically far apart, instead of proving contemporaneity, ought rather to be looked upon as indicative of great discrepancies in the relative epochs of deposit. For in any theory of the origin of species, the spread of any one species, still more of any group of species to a vast distance from the original centre of dispersion, must in most cases have been inconceivably slow. It must have occupied so prolonged a time as to allow of almost indefinite changes in physical geography. A species may have disappeared from its primeval birthplace while it continued to flourish in one or more directions in its outward circle of advance. The date of the first appearance and final extinction of that species would thus differ widely according to the locality at which we might examine its remains.

The grand march of life, in its progress from lower to higher forms, has unquestionably been broadly alike in all quarters of the globe. But nothing seems more certain than that its rate of advance has not everywhere been the same. It has moved unequally over the same region. A certain stage of progress may have been reached in one quarter of the globe thousands of years before it was reached in another; though the same general succession of organic forms might be found in each region.

The geological formations form the records of these ages of organic development. In every country where they are fully displayed, and where they have been properly examined, they can be separated out from each other according to their organic contents. Their relative age within a limited geographical area can be demonstrated by the mere law of superposition. When, however, the formations of distant countries are compared, all that we can safely affirm regarding them is that those containing the same or a representative assemblage of organic remains belong to the same epoch in the history of biological progress in each area. They are *homotaxial*; but we cannot assert that they are contemporaneous, unless we are prepared to include within that term a vague period of perhaps thousands of years.

Doctrine of Colonies.—M. Barrande, the distinguished author of the *Système Silurien de la Bohême*, drew attention more than a quarter of a century ago to certain remarkable intercalations of fossils in the series of Silurian strata of Bohemia. He showed that, while these strata presented a normal succession of organic remains, there were nevertheless exceptional bands, which, containing the fossils of a higher zone, were yet included on different horizons among inferior portions of the series. He termed these precursory bands "colonies," and defined the phenomena as consisting in the partial co-existence of two general faunas, which, considered as a whole, were nevertheless successive. He supposed that during the later stages of his second Silurian fauna in Bohemia the first phases of the third fauna had already appeared, and attained some degree of development in some neighbouring but yet unknown region. At intervals, corresponding doubtless to geographical changes, such as movements of subsidence or elevation, volcanic eruptions, &c., communication was opened between that outer region and the basin of Bohemia. During these intervals a greater or less number of immigrants succeeded in making their way into the Bohemian area, but as the conditions for their prolonged continuance there were not yet favourable, they soon died out, and the normal fauna of the region resumed its occupancy. The deposits formed during these partial interruptions, notably graptolitic schists, accompanied by igneous sheets, contain, besides the invading species, remains of some of the indigenous forms. Eventually, however, on the final extinction of the second fauna, and, we may suppose, on the ultimate demolition of the physical barriers hitherto only occasionally and temporarily broken, the third fauna, which had already sent successive colonies into the Bohemian area, now swarmed into it, and peopled it till the close of the Silurian period.

This original and ingenious doctrine has met with much opposition on the part of geologists and palæontologists. Of the facts cited by M. Barrande there has been no question, but other explanations have been suggested for them. It has been said, for example, that the so-called colonies are merely bands of the Upper Silurian rocks or third fauna, which by great plications have been so folded with the older rocks as to seem regularly interstratified with them. But the author of the *Système Silurien* very justly contends that of such foldings there is no evidence, but that, on the contrary, the sequence of the strata appears normal and undisturbed. Again it has been urged that the difference of organic contents in these so-called colonies is due merely to a difference in the conditions of water and sea-bottom, particular species appearing with the conditions favourable to their spread, and disappearing when these ceased. But this contention is really included in M. Barrande's theory. The species which disappear and reappear in later stages must have existed in the meanwhile outside of the area of deposit, which is precisely what he has sought to establish. Much of the opposition which his views have encountered has probably arisen from the feeling that if they are admitted they must weaken the value of palæontological evidence in defining geological horizons. A palæontologist, who has been accustomed to deal with certain fossils as unfailing indications of particular portions of the geological series, is naturally unwilling to see his generalizations upset by an attempt to show that the fossils may occur on a far earlier horizon.

If, however, we view this question from the broad natural history platform from which it was regarded by M. Barrande, it is impossible not to admit that such phenomena as he has sought to establish in Bohemia must have constantly occurred in all geological periods and in all parts of the world. No one now believes in the sudden extinction and creation of entire faunas. Every great fauna in the earth's history must have gradually grown out of some pre-existing one, and must have insensibly graduated into that which succeeded. The occurrence of two very distinct faunas in two closely consecutive series of strata does not prove that the one abruptly died out and the other suddenly appeared in its place. It only shows, as Darwin has so well enforced, the imperfection of the geological record. In the interval between the formation of two such contrasted groups of rocks the fauna of the lower strata must have continued to exist elsewhere, and gradually to change into the newer facies which appeared when sedimentation recommenced with the upper strata. Distinct zoological provinces have no doubt been separated by narrow barriers in former geological periods, as they still are to-day. There seems, therefore, every probability that such migrations as M. Barrande has supposed in the case of the Silurian fauna of Bohemia have again and again taken place. Two notable examples will be given in later pages, one in the Lower and one in the Upper Old Red Sandstone of Scotland.

Gaps in the Geological Record.—The history of life has been very imperfectly preserved in the stratified parts of the earth's crust. Apart from the fact that, even under the most favourable conditions, only a small proportion of the total flora and fauna of any period could be preserved in the fossil state, enormous gaps occur where no record has been preserved at all. It is as if whole chapters and books were missing from an historical work. Some of these lacunæ are sufficiently obvious. Thus, in some cases, powerful dislocations have thrown considerable portions of the rocks out of sight. Sometimes extensive metamorphism has so affected them that their original characters, including their organic contents, have been destroyed. Oftenest of all, denudation has come into play, and vast masses of fossiliferous rock have been entirely worn away. That this cause has operated frequently is shown by the abundant unconformabilities in the structure of the earth's crust.

While the mere fact that one series of rocks lies unconformably on another proves the lapse of a considerable interval between their respective dates, the relative length of this interval may sometimes be demonstrated by means of fossil evidence and by this alone. Let us suppose, for example, that a certain group of formations has been disturbed, upraised, denuded, and covered unconformably by a second group. In lithological characters the two may closely resemble each other, and there may be nothing to show that the gap represented by their unconformability is not of a trifling character. In many cases, indeed, it would be quite impossible to pronounce any well-grounded judgment as to the amount of interval, even measured by the vague relative standards of geological chronology. But if each group contains a well-preserved suite of organic remains, it may not only be possible, but easy, to say exactly how much of the geological record has been left out between the two sets of formations. By comparing the fossils with those obtained from regions where the geological record is more complete, it may be ascertained perhaps that the lower rocks belong to a certain platform or stage in geological history which for our present purpose we may call D, and that the upper rocks can in like manner be paralleled with stage H. It would be then apparent that at this locality the chronicles of three great geological periods E, F, and G were wanting, which are elsewhere found to be intercalated between D and H. The lapse of time represented by this unconformability would thus be equivalent to that required for the accumulation of the three missing formations in those regions where sedimentation went on undisturbed.

But fossil evidence may be made to prove the existence of gaps which are not otherwise apparent. As has been already remarked, changes in organic forms must, on the whole, have been extremely slow in the geological past. The whole species of a sea-floor could not pass entirely away, and be replaced by other forms, without the lapse of long periods of time. If then among the conformable stratified formations of former ages we encounter sudden and abrupt changes in the facies of the fossils, we may be certain that these must mark omissions in the record, which we may hope to fill in from a more perfect series elsewhere. The complete contrasts between unconformable strata are sufficiently explicable. It is not so easy to give a satisfactory account of those which occur where the beds are strictly conformable, and where no evidence can be observed of any considerable change of physical conditions at the time of deposit. A group of strata having the same general lithological characters throughout may be marked by a great discrepance between the fossils above and below a certain line. A few species may pass from the one into the other, or perhaps every species may be different. In cases of this kind, when proved to be not merely local but persistent over wide areas, we must admit, notwithstanding the apparently undisturbed and continuous character of the original deposition of the strata, that the abrupt transition from the one facies of fossils to the other must represent a long interval of time which has not been recorded by the deposit of strata. Professor Ramsay, who called attention to these gaps, termed them "breaks in the succession of organic remains." He showed that they occur abundantly among the Palæozoic and Secondary rocks of England. It is obvious, of course, that these breaks, even though traceable over wide regions, were not general over the whole globe. There have never been any universal interruptions in the continuity of the chain of being, so far as geological evidence can show. But the physical changes which caused the breaks may have been general over a zoological district or minor region. They no doubt often caused the complete extinction of genera and species which had a small geographical range.

From all these facts it is clear that the geological record, as it now exists, is at the best but an imperfect chronicle of geological history. In no country is it complete. The lacunæ of one region must be supplied from another. Yet in proportion to the geographical distance between the localities where the gaps occur and those whence the missing intervals are supplied, the element of uncertainty in our reading of the record is increased. The most desirable method of research is to exhaust the evidence for each area or province, and to compare the general order of its succession as a whole with that which can be established for other provinces. It is, therefore, only after long and patient observation and comparison that the geological history of different quarters of the globe can be correlated.

Subdivisions of the Geological Record by means of Fossils.—As fossil evidence furnishes a much more satisfactory and widely applicable means of subdividing the stratified rocks of the earth's crust than mere lithological characters, it is made the basis of the geological classification of these rocks. Thus we may find a particular stratum marked by the occurrence in it of various fossils, one or more of which may be distinctive, either from occurring in no other bed above and below, or from special abundance in that stratum. These species might therefore be used as a guide to the occurrence of the bed in question, which might be called by the name of the most abundant species. In this way a geological horizon or zone would be marked off, and geologists would thereafter recognize its exact position in the series of formations. But before such a generalization can be safely made, we must be sure that the species in question really never does appear on any other platform. This evidently demands wide experience over an extended field of observation. The assertion that a particular species occurs only on one horizon manifestly rests on negative evidence as much as on positive. The palæontologist who makes it cannot mean more than that he knows the fossil to lie on that horizon, and that, so far as his own experience and that of others goes, it has never been met with anywhere else. But a single example of the occurrence of the fossil on a different zone would greatly damage the value of his generalization, and a few such cases would demolish it altogether. Hence all such statements ought at first to be made tentatively. To establish a geological horizon on limited fossil evidence, and then to assume the identity of all strata containing the same fossils, is to reason in a circle and to introduce utter confusion into our interpretation of the geological record. The first and fundamental point is to determine accurately the order of superposition of the strata. Until this is done detailed palæontological classification may prove to be worthless. But when once the succession of the rocks has been fixed palæontological evidence may become paramount.

From what has been above advanced it must be evident that, even if the several groups in a formation or system of rocks in any district or country have been minutely subdivided by means of their characteristic fossils, and if, after

the lapse of many years, no discovery has occurred to alter the established order of succession of these fossils, nevertheless the subdivisions can only be held good for the region in which they have been made. They must not be supposed to be strictly applicable everywhere. Advancing into another district or country where the petrographical characters of the same formation or system indicate that the original conditions of deposit must have been very different, we ought to be prepared to find a greater or less departure from the first observed or what might be regarded as the normal order of organic succession. There can be no doubt that the appearance of new organic forms in any locality has been in large measure connected with such physical changes as are indicated by diversities of sedimentary materials and arrangement. The Upper Silurian formations, for example, as studied by Murchison in Shropshire and the adjacent counties, present a clear sequence of strata well defined by characteristic fossils. But within a distance of 60 miles it becomes impossible to establish these subdivisions by fossil evidence. If we examine corresponding strata in Scotland, we find that they contain some fossils which never rise above the Lower Silurian formations in Wales and the west of England. Again, in Bohemia and in Russia we meet with still greater departures from the order of appearance in the original Silurian area, some of the most characteristic Upper Silurian organisms being there found far down beneath strata replete with records of Lower Silurian life. Nevertheless the general succession of life from Lower to Upper Silurian types remains distinctly traceable. Such facts warn us against the danger of being led astray by an artificial precision of palæontological detail. Even where the palæontological sequence is best established, it rests probably in most cases not merely upon the actual chronological succession of organic forms, but also, far more than is usually imagined, upon original accidental differences of local physical conditions. As these conditions have constantly varied from region to region, it must hardly ever happen that the same minute palæontological subdivisions, so important and instructive in themselves, can be identified and paralleled, except over comparatively limited geographical areas.

It cannot be too frequently stated, nor too prominently kept in view, that, although gaps occur in the succession of organic remains as recorded in the rocks, there have been no such blank intervals in the progress of plant and animal life upon the globe. The march of life has been unbroken, onward and upward. Geological history, therefore, if its records in the stratified formations were perfect, ought to show a blending and gradation of epoch with epoch, so that no sharp divisions of its events could be made. But the progress has been constantly interrupted; now by upheaval, now by volcanic outbursts, now by depression. These interruptions serve as natural divisions in the chronicle, and enable the geologist to arrange his history into periods. As the order of succession among stratified rocks was first made out in Europe, and as many of the gaps in that succession were found to be widespread over the European area, the divisions which experience established for that portion of the globe came to be regarded as typical, and the names adopted for them were applied to the rocks of other and far distant regions. This application has brought out the fact that some of the most marked breaks in the European series do not exist elsewhere, and, on the other hand, that some portions of that series are much more complete than in other regions. Hence, while the general similarity of succession may remain, different subdivisions and nomenclature are required as we pass from continent to continent.

A bed, or limited number of beds, characterized by one or more distinctive fossils, is termed a *zone* or *horizon*, and, as already mentioned, is often known by the name of a typical fossil, as the different zones in the Lias are by their special species of ammonite. A series of such zones, united by the occurrence among them of a number of the same species or genera, is called a *group*. A series of groups similarly related constitute a *formation*, and a number of formations may be united into a *system*. The terminology employed in this classification will be discussed in the following part.

PART VI.—STRATIGRAPHICAL GEOLOGY.

This branch of the science arranges the rocks of the earth's crust in the order of their appearance, and interprets the sequence of events of which they form the records. Its province is to cull from all the other departments of geology the facts which may be needed to show what has been the progress of our planet, and of each continent and country, from the earliest times of which the rocks have preserved any memorial. Thus from mineralogy and petrography it obtains information regarding the origin and subsequent mutations of minerals and rocks. From dynamical geology it learns by what agencies the materials of the earth's crust have been formed, altered, broken, upheaved, and melted. From structural geology it understands how these materials were put together so as to build up the complicated crust of the earth. From palæontological geology it receives in well-determined fossil remains a clue by which to discriminate the different stratified formations, and to trace the grand onward march of organized existence upon this planet. Stratigraphical geology thus gathers up the sum of all that is made known by the other departments of the science, and makes it subservient to the interpretation of the geological history of the earth.

The leading principles of stratigraphy may be summed up as follows:—

1. In every stratigraphical research the fundamental requisite is to establish the order of superposition of the strata. Until this is accomplished it is impossible to arrange the dates and make out the sequence of geological history.

2. The stratified portion of the earth's crust, or geological record, as it has been termed, may be subdivided into natural groups or formations of strata, each marked throughout by some common genera or species, or by a general resemblance in the type or character of its organic remains.

3. Many living species of plants and animals can be traced downward through the more recent geological formations; but they grow fewer in number as they are followed into more ancient deposits. With their disappearance we encounter other species and genera which are no longer living. These in turn may be traced backward into earlier formations, till they too cease, and their places are taken by yet older forms. It is thus shown that the stratified rocks contain the records of a gradual progression of organic forms. A species which has once died out does not seem ever to have reappeared. But as has been already pointed out in reference to Barrande's doctrine of colonies, a species may within a limited area appear in a formation older than that of which it is characteristic, having temporarily migrated into the district from some neighbouring region where it had already established itself.

4. When the order of succession of organic remains among the stratified rocks has been determined, they become an invaluable guide in the investigation of the relative age of rocks and the structure of the land. Each zone and formation, being characterized by its own species or genera, may be recognized by their means, and the true succession of strata may thus be confidently established even in a country which has been shattered by dislocation, or where the rocks have been folded and inverted.