TRANSACTIONS
OF THE
EDINBURGH GEOLOGICAL SOCIETY.
SESSIONS 1902-1903, 1903-1904.

XXXI.—*On Unconformities and Palæontological Breaks in Relation to Geological Time.* The Retiring Presidential Address to the Geological Society of Edinburgh, given on the 20th of November 1902. By J. G. GOODCHILD, of the Geological Survey, Royal Scottish Museum, Edinburgh.

IN the course of an Address dealing with the Age of the Earth which I gave before the Royal Physical Society in the Autumn of 1896, an estimate was made, in terms of millions of years, of the interval which separates the Lower Cambrian Period from our own day. That estimate was founded chiefly upon a computation of the time assumed to be required for the deposition of the aggregate thickness of all the normal limestones of marine origin which are known to have come into existence in Western Europe from the commencement of the Cambrian Period down to those forming at the present day. It was assumed, on grounds which were fully stated in that Address, that these limestones, on the whole, had been formed at a rate not essentially different from the mean rate at which there is reason for believing such deposits are forming now. The aggregate thickness of the limestones referred to, multiplied by the rate assumed, gave, as the length of that interval, some 700,000,000 years. I have not yet seen any reason for reducing that estimate.

Since the Address was published some important modifications of many of the older views on the subject of geological time have been adopted by geologists. Some of these changes of opinion are, indeed, of so much importance in the present connection, that I should have felt quite justified in restating the whole of the facts and arguments, and in reviewing them by the light of modern ideas, had there been a suitable opportunity of doing so. But as this, in some respects, is hardly

desirable, I propose to discuss the same question along a different line from the one taken at the former occasion. Accordingly, the present Address is intended to deal mainly with UNCONFORMITIES in relation to Geological Time, as considerations of space obliged me to make little more than a brief reference to that subject in the former Address. In connection with this part of the subject it will be desirable to give as much attention to the palæontological breaks as to the physical, seeing that the full importance of the interruptions in the continuity of the strata cannot be adequately presented for consideration unless the biological evidence is also brought well into view. There are a few collateral subjects which also need to be taken into consideration, amongst which the rate of formation of normal marine limestones must occupy a foremost place.

Regarding this last mentioned subject, the reader of my former Address was asked at the outset to grant four postulates, which, in a slightly different form, may be stated here as follows:—(1) That the formation of calcareous deposits on the ocean floor has been in progress ever since the time when Earth, Air, and Sea finally assumed their existing relative positions. This latter period coincides with the end of what has aptly been termed the Astronomical Phase of the Earth's history. By the foregoing statement it is not intended to convey the idea that deposition has gone on without cessation over one and the same part of the lithosphere throughout all that time; because it is fully recognised that terrestrial undulatory movements have always been in progress, and that it follows as a necessary consequence that the areas of deposit have always been in process of shifting from one part to another. The statement that there has been no break in the continuity of deposition of marine limestones is, therefore, quite warranted, provided it is understood to apply to the ocean floor as a whole. It is also assumed that the terrestrial undulatory movements which affected the level of the ocean floor affected also the temperature of the surface currents, though, of course, in a much less direct way. These, in turn, have affected the rate of deposition of calcareous matter, retarding that rate where cold currents prevailed, and accelerating it where the surface currents were warm. (2) That the primary source of all the calcareous deposits has always been the rocks exposed in the land. In most cases the principal agent concerned in liberating the lime salts has been some micro-organisms, which may be referred to in general terms as "bacteria." These have generated from decomposing organic matter, and from vegetable matter especially, such solvents as the Humus acids, which in the form of

weak solutions in surface waters, have started the chemical changes referred to. The primary source of most of the lime salts in the first instance has been the basic eruptive rocks, whose decomposition is effected mainly by the action of the Humus acids referred to. (3) That the percentage of lime salts contributed by rivers to the ocean from these sources of supply has not materially varied, at any time, if we have regard to the whole area of the Earth. The amount contributed by one river must always have varied, perhaps to a considerable extent, from that poured into the ocean by another—cases which are well exemplified by the respective percentages of lime salts carried into the North Sea now by the River Dee at Aberdeen and by the Thames at Sheerness. Nevertheless, just as uniformity of composition, so far as the percentage of lime salts is concerned, may be said to prevail throughout the parts of the North Sea where these two rivers debouch, so, on the larger scale, in the oceans, the action of surface currents and movements at greater depths, co-operating with diffusive action, soon equalise the amounts. So the defects in one area, however caused, are soon made good by the excess tending to prevail in another. (4) That the average temperature of the oceanic surface waters over what is now Western Europe has at no time varied sufficiently from the theoretical mean proper to the latitudes to cause any excess of deposit at any given time and place: in other words, that tropical conditions have never caused an exceedingly high rate of deposit there.

I venture to assume that these postulates will appear to be perfectly reasonable.

It seems to me that a careful consideration of the foregoing statements ought to convince anyone that we are, therefore, quite justified in attempting an estimate on those bases of what the late Professor John Phillips called the "geological calculus." We need, of course, to take many facts into consideration before proceeding to make such an estimate. The most important of these obviously relates to the quantities of lime salts which the rivers of the present day are annually contributing to the waters of the oceans. We may assume that this quantity is being used up in one way or another, chiefly by organic agencies, as fast as it is brought in; or, in other words, I think that we may assume that the average rate of supply of lime salts in solution affords a reliable measure of the average rate of fixation of carbonate of lime in the solid form. It was chiefly on these grounds that I selected the rate of formation of marine limestones as the basis for the calculations referred to at the commencement of this address. There are other reasons also which can be counted as being in favour of making such use of the data afforded by

limestones; for the liberation of the lime salts must always have been principally due to the chemico-biological action set up in the first instance by micro-organisms, which must have acted in the past much as they do now; and the second part of the cycle of change, that which is involved in the fixation of the lime, being likewise mainly due to chemical changes set up by organic processes, may be presumed also to have obeyed the same laws in the past as it does in the present. The third and remaining part of the cycle of change, involving, in the first place, the re-incorporation of the lime into the materials within the crust of the Earth, including those of the eruptive rocks, and, in the second, the liberation of the CO_2 by volcanoes, must also have gone on in the past at much the same rates that it does at the present day. Moreover, there is yet a further advantage arising from the use of a single group of data, inasmuch as the time scale founded upon these, if proved wrong in any one part, can be raised, or lowered, as the case may be, in the same proportion throughout.

We may now pass on to consider more fully some data which can be made use of in connection with this part of the subject, which, accordingly, are given as follows:—

Recent examinations of the percentages of dissolved substances carried seaward each year by the rivers of the globe have made it evident that, when one area is taken with another, there is an average amount of no less than 53·143 tons of lime salts annually contributed to the stock in the ocean-waters from each square mile of the surface of the land. This quantity is equivalent to 664·3 cubic feet of limestone transferred from the surface of the land to the waters of the sea. If the total quantity thus carried were to be distributed over an area of the sea-bottom equal in extent to that of the land from which it was derived, no less than 41,985 years would be required, at the present average rate of delivery, for the accumulation to that extent of a stratum having a thickness of only a single foot. But as the area of the ocean-floor is much greater than that of the land draining to the sea, and is, in fact, in the proportion of 3·194 of ocean-floor to 1 of land, it necessarily follows that it would require at least three times forty-two thousand years for the accumulation of a stratum of the same thickness. There are, however, several reasons why neither this estimate nor the other quite accords with the facts. In the first place, there is the important fact that the rate of fixation of carbonate of lime in solution through the agency of life is dependent to a considerable extent upon the temperature of the surface waters. Where that temperature is high, organic agencies, in a given time, bring about the fixation of a relatively large quantity of lime, to which quantity locally abstracted

from the surface waters the entire ocean has directly, or indirectly, to contribute. Where the surface waters have a low temperature the supply of lime salts withdrawn is below the mean, and in consequence the surplus from there is available for use elsewhere. It is most likely the case, therefore, that it is only within the temperate zones, or those parts of the Earth's surface with which we are here specially concerned, that the mean rate of deposit of carbonate of lime prevails.

The other chief factor which affects the rate of deposit is that originating through the solvent action which arises from the pressure of the sea water at great depths below the surface. The calcareous exuviae of organisms living in the upper waters of the ocean, slowly descending to greater depths, undergo progressive solution as these are reached. If the carbonate of lime happens to consist of Aragonite, the solution of this is completed by the time the calcareous matter has made its way down to a depth of 1500 fathoms. If the carbonate of lime happens to consist of the more stable Calcite, solution still goes on, but is not completed until a depth of 2900 fathoms has been reached. Hence, although the surface waters of the ocean over these great depressions may teem with life, and an abundance of both calcareous and siliceous matter may be constantly descending from the surface, yet little or none of the calcareous exuviae may reach the bottom, and hence only such siliceous matter as the tests of radiolaria may form the ooze at the bottom. It is on this account that a radiolarian ooze, if it is devoid of calcareous organisms (but not otherwise), is properly regarded as having originated at a depth of not less than 2900 fathoms.

In the case of the redissolved calcareous matter just referred to, we have at present no evidence to show whether it takes the form of the sulphate or of the carbonate: but probably the former.

The foregoing statements relating to the vicissitudes to which calcareous matter is subject in the ocean waters are made here in order to show that the subject is one which is by no means of as simple a nature as many persons have thought. There are, indeed, other disturbing factors than those mentioned, which, it may be repeated here, were duly taken into account in making the original estimate. Hence it will suffice now to give the general results, and, accordingly, to state that, after giving the subject full consideration, I came to the conclusion that a safe estimate for the mean rate of formation of marine limestones, ancient or modern, taking one with another, is one foot in twenty-five thousand years, in the temperate belts of the oceans. If I were inclined to modify that estimate in any way it would certainly be in the direction of increasing

rather than diminishing, the estimate of the number of years required to form the amount in question.

The estimate just given was made on the assumption that the formation of limestone during the deposition of one bed of limestone at a given spot has gone on there without any slackening of pace. But it is doubtful whether this is quite in accordance with what has usually happened. Those who attentively study limestones in the field, and especially those persons who interest themselves in palæontology, must be perfectly well aware of the fact that nearly all limestone rocks are divided up at vertical intervals into beds or posts, each of which has a curious habit of being about two feet in thickness. Those who carefully search limestones for fossils also know very well that above or below one of these posts the fossils are often different, although there is no apparent lithological difference in the rocks above or below the break. Indeed, the top of a post of limestone often marks the highest horizon upon which that fossil occurs. Why is this so? I attempted an answer to that question as far back as 1887 when conducting an excursion of the Geologists' Association over the Tertiary Rocks and the Chalk near Plumstead. It seemed to me then that these interruptions of continuity might be due to some recurrent secular cause. A few years after I expressed that opinion an American writer (whose name I do not at present remember) stated his belief that these breaks might be due to causes connected with precessional changes. The explanation struck me at the time as being worthy of special consideration, and I still think that it will some day, and before long too, attract greater attention than it appears to have done so far. His idea was that alternately warmer and colder surface-currents prevailed as a consequence of these precessional changes, and that more limestone was deposited under the warmer conditions than under the colder. I have developed this idea lately in two or three papers dealing with Graptolite zones, and with some related subjects, to both of which further reference will be made presently.

My Address was published on the 13th of April 1897 (*Proc. Roy. Phys. Soc.*, vol. xiii. pp. 267-271). Fifty days after that date Lord Kelvin addressed the Victoria Institute on the same subject. His Address was published near the close of 1897, when the distinguished author did me the honour of sending me a copy of it. Lord Kelvin's treatment of the subject differed fundamentally from mine; and it is hardly too much to say that his conclusions were almost as different as was his method

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 281

of treating the subject. There is no need here to summarise those conclusions, because the eminence of the writer soon caused his latest views on the Age of the Earth to be very widely known. But their main points may be stated in a few words. (1) The interior of the Earth is now so hot that the time cannot be so very remote since the surface of the Earth was too hot to support life. (2) The Sun is parting with its heat at such a rate that, in this case also, it cannot be so long since the whole of the Solar System formed one great incandescent mass, within which the existence of any form of life was impossible. (3) Therefore geologists err in supposing the Earth to be as old as some of them have thought.

I have no desire to enter upon any controversy upon these points, and it will be quite sufficient for the purpose now in view if I restate, with some little amplification, the substance of the concluding remarks of my Address (*op. cit.*, pp. 307-8) as follows:—(1) It is by no means certain that the heat met with in deep borings into the Earth's crust represents wholly, or perhaps even in part, any vestige of the Earth's primæval heat of consolidation. It is much more likely that the heat in question is largely due to earth-movements now, or recently, in progress—or, in other words, that it is of dynamic origin.¹ It may well be the case that a subterranean temperature little short of that of the primæval consolidation of the Earth's crust has been generated again and again, even within geological times quite recent, in connection with some of the great earth-movements which are well known to have taken place. On this view of the matter, the curious diversities in the results observed in connection with the temperature found in boreholes, as well as the equally remarkable diversities noticed within the crust at places far apart, can be readily enough accounted for. Nobody doubts that heat does flow at a certain rate through a given thickness of a particular kind of rock. The real question, however, is not that, but whether the heat observed in each case was generated there very long ago, or within times which are, geologically speaking, quite recent. It seems to me inevitable that the geo-isotherms must rise above their normal position within the Earth's crust wherever terrestrial movements are in progress. Whether these movements are caused in part by the unequal loading of the Earth occasioned by denudation on the one hand and deposition on the other; or whether they may be due in part to luni-solar gravitational effects; or again, whether they are due, also in part, to the Earth's interior being a vast magnet, which is pulled this way

¹ See "On the Maintenance of the Earth's Internal Heat" (*Proc. Roy. Phys. Soc.*, vol. xiv. pp. 157-8).

or that under certain conditions of the solar orb—the fact still remains that the movements referred to can be demonstrated to have always been going on in the past, and that, indeed, they are still in progress in one part or another. It is a fallacy, therefore, to argue that because the temperature of the Earth's interior is so-and-so at such a depth, that it cannot be so long since the Earth was red-hot.

The other objection to any high estimate of the Earth's antiquity as an abode of life is founded upon the rate at which the Sun is thought to be dissipating his energy into space. Granting the premises advanced by those who take that view, there cannot well be much doubt regarding the possibility of the Sun's age being even less than Lord Kelvin was inclined to regard it. On further consideration of this important question, however, it will be seen to be one that admits of several different answers. Some persons may be inclined to think regarding it that the prevalent idea that solar energy is dissipated indifferently at the same rate in all directions into space is one that is based more upon assumption than upon proof. So far as I am able to judge, no valid evidence has yet been adduced against the view that the Sun does not lose heat, for example, by radiation in any direction except that in which lie material bodies; and, even in the case of them, that the loss occasioned by this radiation follows the law of inverse squares in relation to the distance of the body receiving that heat. Thus, in the case of two stellar bodies of the same temperature and of equal volume, but of which the distance of the one is twice that of the other, the more distant body occasions the loss of only one-fourth of the Sun's heat which is caused by the other which is at unit distance. Therefore, it seems to me, unless the contrary can be proved, any objection to the great antiquity of life upon the Earth based upon the rate of loss of the Sun's heat may be put aside in the present case.¹

[Recent discoveries connected with the behaviour of various radio-active bodies have led to our viewing these matters in an entirely different aspect. It is now known that many substances possess the property of giving forth apparently illimitable stores of energy. Hence, assuming that some of these radio-active substances enter into the composition of the Sun, it is more than likely (altogether apart from the speculations set forth above) that the Sun has continued to give forth light,

¹ It is proper to state here that the foregoing remarks formed part of the Address actually delivered before the Edinburgh Geological Society, and have been left here nearly as they were said on that occasion. The paragraph in square brackets has been added to the manuscript since then.—J. G. G., November 1903.

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 283

heat, and other forms of energy, at the present rate, for a period of far greater length than any that geologists are ever likely to require in order to account for the changes that have taken place upon the Earth since the close of its astronomical history. This leads me to remark that had we known in 1896 what we now do about the important part taken by radio-activity in such matters as those under consideration, it could hardly have happened that one of the most distinguished of our British field-geologists would have remarked, in a discussion that took place regarding the Address to the Royal Physical Society, that he would accept my estimate of the age of the Lower Cambrian sediments if I would cut off two cyphers from the end of the 700,000,000 years at which my estimate of that age was therein stated.]

One cannot shake off the impression that much of the unwillingness on the part of some really scientific men to accept so high an estimate of the Earth's Age arises from the same feeling as that which influenced mediæval savants in their attitude towards the statements which were then beginning to be made with regard to the distances of the planetary and stellar bodies. It is hardly likely that nowadays any sane person can be found who would even think of questioning those estimates, even though it is well known that most of them are computed from angular measurements founded upon a relatively small base-line. A consideration of the real nature of some of these astronomical measurements may be usefully made from the table given here, which is as follows:—

Distances subtended by one second of arc from base-lines of various lengths:—

<i>Base-line of:—</i>	<i>Distance represented:—</i>
One inch,	3 miles, 218' = 18,022 feet.
One foot,	39 miles, 24'
One mile,	206,264,808 miles.
The Earth's diameter (7926 miles),	1,634,890,464 "
The Earth's mean distance from the Sun,	19,161,256,808,000 "
The mean diameter of the Earth's orbit,	38,322,513,616,000 "

The distance of *α centauri*, the nearest star, has been measured from the last-mentioned base, which subtends an angle of 0".75, or three-quarters of a second of arc, and the estimate thus arrived at is accepted on all hands as virtually correct. Astronomy, however, is a science of long standing, and, consequently, intellectual people are now quite willing to accept any statements regarding either the magnitudes or the distances of the stellar bodies that astronomers of good authority see fit to

make, even though the figures may refer to magnitudes much too vast for the human intellect to comprehend. On the other hand, the sister science Geology was hardly thought of before the Nineteenth Century; and consequently there are many persons, even amongst the well-informed, who, while they are quite willing to accept almost any statements regarding astronomical distances, yet persistently decline even to consider any figures of great magnitude relating to geological time.

It will readily be seen that an enquiry like the present one might follow any one of various different lines. We might seek, as Croll and others have actually done, for some geological evidence of the recurrence of such conditions as could safely be connected with recurrent phenomena of an astronomical nature, and whose periods admit of being computed. A suggestion made on these lines has already been given in the introductory part of this Address. Such a line of enquiry promises to give trustworthy results; but the difficulty at present is that we have not enough data to work upon; we have, so to speak, measured our angles, but we are not quite sure about the base-line. In another direction we might collect a series of observations upon the rate at which certain forms of life have changed in a given interval under conditions more or less well known, and thereon base a calculation of the rate at which similar changes in the organic world have proceeded in a given recent geological period. For instance, the whole of Etna is believed to have grown up since the Newer Pliocene Period, because the earliest of its volcanic rocks are certainly based upon, and interstratified with, rocks containing fossils which are regarded by competent authorities as belonging to that geological period. Yet it can be shown that the changes in the organic world which have taken place between that time and now, even amongst the Mammalia and the plants, have been so trifling in amount that organic mutations to an equal extent would be likely to be passed over as insignificant if they were met with in some of the older rocks. Yet it is supposed, with good reason, that organic changes, especially in the higher forms of life, go on with more rapidity now than they did in the earlier periods of geological history. Etna has grown to an elevation of about eleven thousand feet above the sea. But its rate of growth has not been by any means uniform, and that rate must have varied much from time to time, for there have been long periods of quiescence, and eviscerations on a large scale have undone much of the work accomplished by previous eruptions; yet, if we assume

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 285

that volcanic action has gone on in the past, even at the rate it has since the dawn of history, the antiquity of that colossal volcano must be very considerable when estimated by the ordinary standards of chronology. It must be remembered, in computing the rate of growth of a volcano which consists, as Etna does, chiefly of rocks of effusive origin, that the growth in question is accomplished mainly by the deposition of narrow streams, or streaks as they might be called, of lava, each of which is radial to the centre of eruption. Freshly emitted lava, being fluid, and thus obeying the laws of motion of a fluid, invariably flows downhill, or in the direction of the lowest ground adjacent. Hence, any individual lava stream, once it has been formed, cannot be surmounted by another one until the marginal areas adjacent to its sides have been levelled up to its own height. From this it is evident that, though an enormous volume of rock may be deposited within a small area, even in a few days, yet a very long time must elapse before that lava stream can be covered by another flow of later date. We know that where some of the great chestnut trees grow on the flanks of Etna that there has been no deposit of volcanic material where they stand during the many centuries since they first began to grow. It was, I think, on some such grounds as these, that Professor Lloyd Morgan, in his articles on "Geological Time," *Geol. Mag.*, Dec. 2, vol. v. p. 204 (1878), based his very moderate estimate of the rate of growth of large volcanoes in general at one foot in three hundred years. It may be true that a certain amount of distension of a volcanic cone is sometimes occasioned by the forces which emanate from the central pipe; but, on the other hand, central subsidence, contemporary denudation, and repeated evisceration probably more than counterbalance that. If, therefore, we take the height of the volcanic part of Etna at ten thousand feet, its age, on this estimate, must be three million years. In the meantime, as we know from a comparison of the fossils occurring in the Newer Pleiocene rocks of Britain,¹ that the changes which have taken place in the organic world, so far as Western Europe is concerned, since the Newer Pleiocene Period, have been of so trifling a nature that they would have been likely to be ignored entirely had they been under consideration in connection with some of the older geological formations. Yet the whole of the events which occurred during the Age of Snow have happened since, as also have the numerous and important changes which followed the close of that period. Surely one would have expected that the complex

¹ See Clement Reid's numerous and valuable contributions to the literature of this subject.

expatriations and impatriations of plants and animals which resulted from these changes of climate would have left a stronger mark upon the fauna, and especially upon the flora, than they have done, had the rate of organic change really been as high as is commonly supposed. Hence, in considering the great biological changes which are made known to us by the palæontological records, we can hardly fail to realise that these mutations are due quite as much to secular causes as to changes of environment. In other words, these changes in the organic world necessarily imply the lapse of long periods of time.

There still remains the other line of enquiry, which may be regarded as running parallel to those which have been already referred to. This relates to the numerous breaks in the continuity of deposition which locally occur on one horizon or another throughout the whole geological series. As these physical breaks are, in a great many cases, closely connected with changes in the biological world of more or less importance, and as both of these imply the lapse of considerable periods of time, the two subjects must be considered together, so that their joint bearing upon the subject specially under consideration may be rendered quite evident.

One set of rocks is unconformable to another in all cases in which one or more other geological formations elsewhere intervenes, whether there is a discordance of dip between the two or not. Thus modern alluvium lying upon the Norfolk Forest Bed, does so, in this sense, unconformably, although there may be, and usually is, absolute conformity between the two, so far as their relative dips are concerned. As pointed out above, the whole of Etna has come into being in the interval represented by the plane of junction between the two. Important groups of mammalia have come and gone, and the configuration of large tracts of country, in the meantime, has undergone changes of great importance. The Mastodon has disappeared; two or three species of Elephant and Rhinoceros have followed each other and successively died out; several species of Deer have come and gone; an important migration of arctic plants and animals, first to the South, and then back to the North, has taken place; Man has appeared, and has gone through many important stages of intellectual development—and all this has happened in an interval which, at the first glance, appears to be represented, in the case cited, by one continuous series of deposits. Indeed, a break of the same nature met with in rocks of whose relative histories less were known, would certainly be passed over as quite unimportant. Yet that break between the modern Norfolk alluvium and the old alluvium

of the Newer Pleiocene Rhine may well represent some three millions of years, although, as above stated, there is apparently no want of conformity between the older alluvium and its modern representative.

It is usual to judge of the respective ages of two associated strata of Tertiary age (as, for example, in the case just cited), by making a comparison, in the case of the fossils yielded by each, of the relative proportions of existing species of mollusca found in the fossil state in these rocks to those which are extinct. The older deposit has the larger percentage of extinct species, and the relative proportion of extinct to recent serves to fix the absolute geological position of either or both. The test is an excellent one so far as it goes, and it offers the great advantage in most cases of being easily applied. All the same, geologists in general will be inclined to agree with Gaudry, Boyd Dawkins, Forsyth Major, and others, in regarding the succession of mammalian life, as affording, on the whole, more satisfactory criteria for making the determination in question. I support this now, notwithstanding the fact that, while I have collected thousands of mollusca from the Tertiary rocks on all horizons, yet below the Newer Pliocene rocks I have never met with even a fragment of a mammalian skeleton. Instead, therefore, of giving a list of the zonal fossils of the Tertiary Rocks from the Mollusca, I here give a short one of the Mammalia, because the replacement of one genus or species by another, when the newer strata are compared with the older, brings the time required for the change into the greater prominence.

The following list gives the geological date of the first appearance of some of

the leading genera of mammalia found in a fossil state in Western Europe. This may be regarded as a list of the zonal forms :—

F. LATE PLEIOCENE TO RECENT.—*Arvicola*, *Capra*, *Megaceros*, *Gulo*, *Lutra*, *Ovibos*, *Spermophilus*, *Talpa*, *Vulpes*, *Sorex*, *Phoca*, and (?) *Homo*.

E. PLEIOCENE.—*Elephas*, *Felis*, *Equus*, *Hippopotamus*, *Trogontherium*, *Castor*, *Bos*, *Cervus* (and allied genera), *Bison*, *Arctomys*, *Sus*, *Tapirus*, *Ursus*, *Balænodon*, *Ziphius*, *Chonoziphius*, *Balæna*, *Balænopterus*.

D. MIOCENE.—*Anchitherium*, *Deinotherium*, *Mastodon*, *Oreopithecus*, *Hyotherium*, *Machairodus*, *Toxodon*, *Dryopithecus*, *Hyænartcos*, *Hipparion*, *Dorcatherium*, *Rhinoceras*, *Lagomys*, *Simocyon*, *Ancylotherium*, *Leptodon*, *Tragoceras*, *Helladotherium*, *Ictitherium*, *Hyæna*, *Antilope*, *Squalodon*.

C. OLIGOCENE.—*Anoplotherium*, *Xiphodon*, *Chæropotamus*, *Acrotherium*, *Cainotherium*, *Amphimeryx*, *Hyænodon*, *Adapis*, *Hyopotamus*, *Anthracotheium*, *Hyrachius*, *Dremotherium*, *Gelocus*, *Chalicotherium*, *Tapirus*, (?) *Vespertilio*, and others.

B. UPPER EOCENE.—*Palæotherium*, *Paloplotherium*, *Lophiodon*, *Pterodon*, *Cænopithecus*, *Hyopotamus*, *Dichobune*, *Amphicyon*, *Cynodon*, *Microcerus*, *Sciuroides*, etc.

A. LOWER EOCENE.—*Arctocyon*, *Coryphodon*, *Hyracotherium*, *Pliolophus*, and *Halitherium*.

In considering this list one has to bear in mind the fact that it includes, incidentally, a number of species of mammalia which mark successive stages in the evolution of the forms now in existence; and also to remember that others in the list are annectant forms between groups which are now widely separated; and, furthermore, that many of them, as they are traced backward in time, show an unmistakable tendency towards generalised forms of lower grade than those which succeeded them. In most cases this morphological feature grades in the direction of the Insectivora or even to that of the Marsupials.

I have dwelt much more upon this striking piece of evidence of the great length of time represented by the various palæontological changes, than upon the quantity of material removed by denudation between one interval and another, which, in Western Europe, at all events, is by no means large in amount. A reference to the diagram given at the end of this paper will serve to indicate the main features in this connection; so that I need not dwell upon that part of the subject here. But the reader may be further reminded that the very materials that compose several important mountain chains had not undergone even deposition until a period late in the history of the Tertiary

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 289

strata. Moreover, some of the most stupendous changes of level of the Earth's crust have also taken place since nearly all our existing genera, and even many of the existing species, of marine mollusca have come into existence. Witness, for example, the enormous amount of terrestrial disturbance which the Tertiary rocks have undergone in comparatively recent times in the Himalaya Mountains and elsewhere. In these and other cases, deposits formed in deep water have been elevated three or four miles above the level at which they were formed. See also the enormous accumulations of volcanic material that remain, even yet, in the British Isles and else-

FIG. 2.—DIAGRAM ILLUSTRATING SEVERAL PHASES OF UPHEAVAL AND DENUDATION WHICH LEAD TO UNCONFORMITIES.

where, and out of which, since the volcanoes ceased to be active, some of the largest valleys in the kingdom have been slowly excavated by sub-aerial forces, largely by prolonged bacterial action. Bearing these facts in mind, should the geologist be startled by my estimate of the time required for the accomplishment of what took place during the Tertiary Period, if it amounts to the large figure of some ninety-three millions of years?

Leaving the reader to reflect upon these statements, and to extend his ideas thereon by the help of the diagram at the end of this article, I will pass on to consider the unconformity which occurs at the base of the lowest of our British Tertiary Rocks—the Thanet Sands. I happen to be well acquainted with almost every natural exposure of that rock, and have in former years devoted much study in the field to its relation to

the Chalk upon which it lies. Text-books on Geology usually describe this junction as one which marks "the greatest unconformity in the whole geological series." For my part, I have never been able to see anything more than evidence of the removal of a small thickness of the Chalk—two or three hundred feet or so, at the very outside. Nor can I persuade myself that the palæontological break is really anything like as important as people have supposed. A careful and unprejudiced study of the evidence points to the fact that nearly all the organisms which are specially characteristic of the Cretaceous Rocks in general died out before the Chalk ceased to be formed, that is to say, within the Cretaceous Period itself. Most of the other facts of this nature (not all, of course) can be readily explained by attributing the changes in the organic world that took place here, about this period, to the combined effects arising from changes in the depth of the sea and a lowering of the temperature of the surface waters. It is not meant by this that there is no evidence of the effects of time to be seen, but only that the chronological break between the Cretaceous and the Tertiary Rocks in Britain has been vastly overrated. A careful comparison of the Lower Tertiary Mollusca with those which lived under similar conditions in the early part of the Cretaceous Period will suffice to show that the break, so far as these are concerned, is hardly more than might have been expected to occur if we have regard to the enormous length of time which must have been required for the accumulation of the Chalk itself.

The Cretaceous rocks in some parts of the Mediterranean area consist of crystalline limestones of marine origin, whose thickness may reach to as much as 4000 feet. Even in such cases as those we are not quite sure about either the upper limit or the lower. If we go upon the principle of taking the maximum thickness as affording material for an estimate of the time required for the formation of these rocks, the reader will agree with me that the estimate I originally made regarding the time required for the formation of the English Chalk, *i.e.* 27,500,000, as being below rather than above the truth.

The Western European Cretaceous Rocks are wholly of marine origin, and were formed, for the most part, at some distance from land, and also, I think, in moderately deep water. Therefore we lose sight of any mammalia that may have been in existence, and are compelled now to rely upon changes in the invertebrata for evidence of lapse of time. Looking at the palæontology first in a very general way, it becomes evident that the close of the Cretaceous Period

marked, on the one hand, the first appearance here of the Dicotyledonous Angiosperms; and, on the other hand, the last appearance of such Reptiles as the Enaliosaurians, the Pterosaurians, and the Dinosaurians, of such Cephalopoda as the Ammonites, Belemnites, and Baculites, of the Rudistes amongst the Mollusca, and of the Echinoconidæ amongst the Echinoderma.

Taking the Cretaceous Rocks as ranging from the beds on the horizon of the base of the Gault to the highest Chalk existing on the Continent, we find that there are 29 zones, each of which is characterised by its own fossils. As these facts bring vividly before the eye the enormous length of time which the Cretaceous Rocks represent, the lists of those zonal fossils may well be stated here. The highest zones are given first:—(29) *Nautilus danicus*; (28) *Baculites anceps*; (27) *Ostrea lunata*; (26) *Belemnitella mucronata*, with *Magas pumila* and *Heteroceras polyplacum*; (25) *Belemnitella quadrata*; (24) *Marsupites ornatus* (and allied species); (23) *Micraster coranguinum*; (22) *M. cor-testudinarium*; (21) *Holaster planus*; (20) *Terebratulina gracilis*, with *Echinoconus subrotundus*; (19) *Rhynchonella cuvieri*; (18) *Inoceramus labiatus*, *Cardiaster pygmaeus*, and *Hippurites*; (17) *Belemnitella plena*; (16) *Ammonites rothomagensis*; (15) *Holaster subglobosus*; (14) *Ammonites varians*, *Rhynchonella martini*, with *Scaphites æqualis*, *Turritiles costatus*, and *Inoceramus latus*; (13) *Plocoscyphia meandrina*; (12) *Pecten asper*, *Exogyra columba*, *E. conica*, with *Catopygus carinatus* and *Pecten quinquecostatus*; (11) *Ammonites inflatus*, *A. rostratus*; (10) *Kingena lima*; (9) *Ammonites varicosus*, with *Inoceramus sulcatus*; (8) *A. cristatus*; (7) *A. auritus*; (6) *A. denarius*; (5) *A. laurus*; (4) *A. delaruci*; (3) *Palæocorystes stokesii* and *P. broderipi*, etc.; (2) *Turritiles elegans*; (1) *A. interruptus*.

In the Mediterranean region, which formed a different zoological province from the British one during the Cretaceous Period, the palæontological evidence, as well as the vast thickness of the limestones, fully bears out the statements already made regarding the enormous length of time required for the accumulation of these deposits. For the object at present in view, it is of considerable importance to dwell at some length upon this feature, because the physical breaks that ensued after the close of Cretaceous times were, in most cases, apparently but trifling in amount, and they certainly could not of themselves convey to the mind of the geologist any adequate conception of the length of time which the other facts bring so vividly into view.

When we reach the base of the true Cretaceous Rocks (here
VOL. VIII. PART III. B

taken to be *above* the Lower Greensand), we meet with the first clear evidence of an extensive and widespread unconformity. That base may lie indifferently upon any rock older than itself, from the highest of the Neocomian strata, which it does with seeming conformity at several places, down to rocks of Archæan age. Even in Britain the Cretaceous Rocks of Argyllshire and Inverness lie, in places, upon the edges of rocks as old as the Moine Schists. Moreover, the plane of unconformity is one of remarkable evenness. [I may be permitted to remind the reader at this point that, as far back as August 1880 (see the *Carlisle Patriot* for that month), I suggested that the plain of the mountain tops in North Britain was a "modified descendant of this Pre-Cretaceous Plain, re-exposed by the upheaval of the Cretaceous Rocks and their subsequent removal by denudation since Miocene times."] The nature of that plain may be understood by reference to Fig. 3, which has been lent to me by the author of "The Geology of England and Wales," and, even better, by a study of the photograph taken near Weymouth, by Aubrey Strahan, F.R.S. See Plate VII., Fig. *a*.

In both of these the Cretaceous beds are shown overstepping various older rocks, from the Wealden beds downward. Mr Woodward's figure shows that the chief break lies between the Aptian (or the Lower Greensand) and the Wealden Rocks. There is, however, some evidence of true unconformity also between the Cretaceous Rocks and the Lower Greensand. The Wealden Rocks evidently form the upward continuation of the Jurassic strata; while the Lower Greensand appears to belong to a separate formation, to which the term Aptian should be restricted. There is, however, still some difference of opinion regarding the horizon upon which the limits, above and below, of either the Aptian or of the true Neocomian Rocks. Probably the reason may be that the Alpine types of these rocks represent the results of continuous deposition which went on there while upheaval and denudation were in progress in Britain. I wish to direct special attention to this point, because the chronological value of the break at the base of the Gault can be estimated better by reference in the first instance to the fact that several thousand feet of marine strata, including many thick masses of marine limestone, were accumulated in the area represented now by South-Western Europe, about the time that the unconformity was in progress here; and, in the second instance, to the important biological changes which are known to have been accomplished in the same interval. The period in question coincides with the first appearance here of the Hippuritidæ, the Spatangidæ, of *Terebratella*, and of Teleostean fishes of the types

Trans. Geol. Soc. Edin., Vol. VIII., Plate VII.

Fig. *a*.—Cretaceous Rocks lying unconformably upon Jurassic Rocks,
near Weymouth.

Fig. *b*.—Tertiary Basalts on Upper Greensand, on ?Rhætic Cornstones,
on Quartzites of the Highland Schists. Shore of Mull, opposite
Inch Kenneth.

which prevail now. Five palæontological zones are usually recognised, which, stated in descending order, are as follows:— (5) *Belemnites minimus*; (4) *B. semicanaliculatus*, *Perna mulleti*, *Ecogyra sinuata*, and *Ammonites deshayesi*; (3) *Belemnites jaculum*, *Ancylloceras duvalii*, *Crioceras emericii*, *Macroscaphites yvanii*, *Ammonites speetonensis*, *Ecogyra subplicata*, *Pecten cinctus*; (2) *Ammonites noricus*; (1) *Belemnites lateralis*, *B. dilatatus*, *Ammonites astierianus*, *Toxaster complanatus*, *Ecogyra couloni*, *Ostrea macroptera*. I am content to let this evidence of the deposition of thick masses of marine limestone on the one hand, and the evolution of numerous and important changes in the organic world on the other, express the chronological value of the unconformity which is under consideration.

I should prefer to group all the strata from the highest of the Wealden Rocks down to the top of the Rhætic Beds as Jurassic, seeing that there is evidence of deposition without any break worth taking into account here, and because the evolution of one fauna and flora after another throughout the various horizons of these rocks seems also to have been continuous. But as the Cretaceous Rocks lie upon the Rhætic Rocks, or upon one part or the other of the Upper, or even of the Lower, New Red, one has to take into account, if only in a general way, the further evidence of lapse of time implied by the unconformity when it is of this kind. As examples of cases of the kind referred to, I may cite that on the coast at Sidmouth, that at several localities near Belfast, and the one less known, which is represented in Plate VII., Fig. 6, from a photograph taken by David Russell of Markinch. In this latter, which is on the west coast of Mull, close to Inch-kenneth, the Cretaceous Rocks belonging to zone 12 (see *ante*) are capped directly by the Tertiary basalts, and lie, in their turn, upon Cornstones, which seem to pertain to the Rhætic Rocks. These, again, repose on the upturned ends of quartzites belonging, apparently, to an horizon low down in the great metamorphosed group of sediments which form the Scottish Southern Highlands. Four great unconformities thus come into view in one exposure. It may be remarked here that, in reference to sections like this, some geologists would suppose that no rocks had ever been deposited upon the Highland Schists until Rhætic times, and thus assume that these rocks had formed a land area throughout all the intervening period. I will merely call attention to this way of looking at the matter, without adding any further remark.

In regard to the broader palæontological features presented by the Jurassic Rocks, as here defined, it will be enough if the reader is reminded of the varied succession of Reptilian life, of the abundance and variety of the Cephalopoda, and of the

FIG. 3.—DIAGRAMMATIC SECTION TO SHOW THE PHYSICAL RELATION BETWEEN THE CRETACEOUS ROCKS AND THE LOWER GREENSAND TO THE JURASSIC ROCKS IN WILTSHIRE.—From Woodward's *Geology of England and Wales*.

important changes that went on in almost every section of the organic kingdom in the time referred to.

Leaving the marine equivalents of the Wealden Rocks out of account, we may recognise in the Jurassic Rocks the following thirty zones, which are given, as before, from the highest downwards:—(30) *Ammonites gigas*, *A. biplex*, *A. portlandicus*, *Ostrea expansa*, *Cardium dissimile*, *Trigonia gibbosa*, *Terebratula diphya*; (29) *Exogyra virgula*, *Pteroceras oceanii*, *Ammonites alternans*, *Diceras arietinum*, *Ostrea deltoides*, with *Rhynchonella inconstans* and *Trigonia incurva*; (28) *Cidaris florigemma*, *Ammonites plicatilis*; (27) *Ammonites perarmatus*, *A. cordatus*, *Ostrea gregaria*, and *Belemnites abbreviatus*; (26) *Ammonites athleta*, with *A. duncani*, *A. cordatus*, *A. jason*, *Belemnites hastatus*, *B. sulcatus*, *B. oweni*, and *B. anomalous*; (25) *Ammonites macrocephalus*, with *Trigonia costata*, *Belemnites parallelus*, *Ostrea sowerbyi*, *Pecten fibrosus*, *Terebratula maxillata*, *T. digona*, *Rhynchonella concinna*, and *Clypeus plotti*; (24) *Ammonites aspidioides*, with *Terebratula lagenalis*, *Monotis echinata*, and *Trigonia litterata*; (23) *Ammonites ferrugineus*, with *Terebratula coarctata* and *Ostrea knorri*; (22) *Ammonites parkinsoni*, with *Trigonia striata*; (21) *Ammonites humphreysianus*, with *Terebratula fimbria*, *Rhynchonella spinosa*, *Belemnites elongatus*, *Trigonia signata*, and *Ostrea acuminata*; (20) *Ammonites sauzei*, with *Ostrea marshi*, *Trigonia costata*, *Belemnites digitalis*; (19) *Ammonites sowerbyi*, *Belemnites giganteus*; (18) *Ammonites munchisoni*, *Trigonia v-costata*; (17) *Ammonites opalinus*, *Trigonia navis*, with *Belemnites irregularis* and *Rhynchonella cynocephala*; (16) *Ammonites jurensis*, with *A. radians* and *A. communis*, and with *Belemnites irregularis* and *B. voltzii*; (15) *Ammonites bifrons*, *Posidonomya bronni*, with *Gryphæa arcuata* and *Leda ovum*; (14) *Ammonites serpentinus*; (13) *Ammonites spinatus*, with *Pecten æquivalvis*; (12) *Am-*

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 295

monites margaritatus, *Belemnites paxillosus*, with *Cardium truncatum*, *Avicula cygnipes*, and *Rhynchonella tetrahedra*; (11) *Ammonites capricornus*, with *A. henleyi*, *A. davei*, *A. fimbriatus*, and *Belemnites milleri*; (10) *Ammonites ibex*, with *Belemnites penicillatus*; (9) *Ammonites jamesoni*, with *Belemnites elongatus*; (8) *Ammonites raricostatus*, *A. armatus*, with *Hippopodium ponderosum*; (7) *Ammonites oxynotus*; (6) *Ammonites obtusus*, with *A. planicostatus* and *Belemnites acutus*, *B. clavatus*, and *Cardinia listeri*; (5) *Ammonites semicostatus*; (4) *Ammonites turneri*, with *Avicula inaequivalvis*; (3) *Ammonites bucklandi*, with *Belemnites clavatus*, *B. acutus*, *Lima gigantea*, and *Spiriferina walcotti*; (2) *Ammonites angulatus*; (1) *Ammonites planorbis* and *Ostrea liassica*.

With regard to the extraordinarily limited vertical distribution of some of the fossils mentioned in the foregoing list, it is difficult to form an opinion as to how far lapse of time alone will suffice to account for the repeated substitution of one species for another, in successive periods represented, in many cases, by but a small thickness of strata; or how far changes of environment have been, in part, concerned in bringing about these most interesting mutations. It has to be constantly borne in mind in this connection that the early, or larval, stages of a great number of marine animals are passed near the surface of the ocean, and that many of the fry of these animals are extremely sensitive to changes of temperature of these surface-waters. If, therefore, it has happened in the past, as certainly does occur now, that a region characterised at one period by warm surface-waters afterwards experiences one of a colder character, it is quite conceivable that such of the fry as are more susceptible to the effects of cold might be killed off each year during the breeding season, and thus that particular species might eventually become extinct. At subsequent periods allied species, coming gradually to occupy the position abandoned by the one that has locally disappeared, brought in new morphological characters, whose development, though due largely to the influence of time, have been somewhat accelerated in consequence of the changes in environment involved in the migration. It is at least possible that each of these mutations may have been partly occasioned by precessional causes, as suggested above.

In Devonshire, rocks of Cretaceous age are said to lie directly upon those belonging to the Carboniferous beds. In this case we have to consider the time required for the formation of all the missing rocks of Post-Carboniferous age, seeing that no unconformity of any moment occurs in Britain on any geological horizon between the base of the

Lower New Red or Dyas and the base of the Neocomian Rocks. In taking these facts into account, we are bound to consider the maximum thickness of rocks of marine origin which can be shown to have been formed in the interval in question, otherwise we shall not obtain a correct idea of the full extent of this great break. Beginning with the Rhætic Rocks, we find that these are represented in Tyrol and Styria by a thick series of marine limestones of deep-water origin, which are characterised over a far wider area than that just referred to by the presence of *Avicula contorta*, *Cardium rhæticum*, *Pecten valoniensis*, and, in some parts, also by *Megalodon triqueter*. Below the Rhætic Rocks occurs the marine equivalent of the Upper New Red (which latter is of continental origin—partly found in desert areas—over much of Western Europe). I have suggested that we might advantageously take the marine type of development as the standard one, in such cases as those of both the New Red and the Old Red, and that we should refer to the marine equivalent of the Upper New Red as the TYROLIAN, with reference to the district where it is best developed. There are eleven well-marked palæontological zones in the Tyrolian Rocks, whose characteristic and prevalent fossils may be given here, and in the order adapted in the case of the other formations already noticed:—(11) *Turbo solitarius* and *Avicula exilis*; (10) *Trachyceras aonoides*; (9) *Tropites sub-bullatus*, *Trachyceras aon*; (8) *Didymites tectus*, *Trachyceras archelaus*; (7) *Arcestes ruber*, *Daonella lommeli*; (6) *Pinacoceras parma*; (5) *P. metternichi*, *Trachyceras reitzi*; (4) *Choristoceras haueri*, *Ch. curionii*; (3) *Ceratites trinodosus*; (2) *C. binodosus*, *Encrinurus liliiformis*, and *Terebratula vulgaris*; (1) *Tirolites cassianus*, *Naticella costata*, and *Myophoria costata*.

The limestones in the Tyrolian series have been formed to a large extent by lime-secreting Algæ, amongst which *Gyroporella* and *Diplopora* play a very important part. In the Mediterranean type of these rocks, which may have formed a separate zoological province of the Alpine area at the time, thirteen zones can be made out. These, beginning with the latest, as usual, may well be given here:—(13) *Sirenites argonautæ*; (12) *Pinacoceras metternichi*; (11) *Cyrtopleurites bicrenatus*; (10) *Cladistes ruber*; (9) *Sagenites giebeli*; (8) *Tropites subbullatus*; (7) *Trachyceras aonoides*; (6) *Tr. aon*; (5) *Protrachyceras archelaus*; (4) *Pr. curionii*; (3) *Ceratites trinodosus*; (2) *C. binodosus*; (1) *Tirolites cassianus*.

The Tyrolian Period may be termed, with good reason, The Age of Ammonites. We are not, however, so much concerned here with the general palæontology of the Tyrolian Rocks, whether formed in the deep sea or on the desert areas con-

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 297

temporary with these marine phases, so much as we are with the perfectly-clear evidence of the lapse of time. We are apt to lose sight of this important fact when we are looking at a section in which rocks of Cretaceous age lie directly upon, let us say, Carboniferous strata, as in the case just cited.

But we have not yet completed our tale of the rocks missing in a case such as that just referred to. In Britain the desert-formed Upper New Red or Trias graduates downward in places into an older set of rocks, which were also mainly formed under desert conditions. I refer to the Lower New Red or Dyas—the so-called “Permian.” No unconformity worth more than a casual reference occurs between the Upper New Red and the Lower—except in text-books—for I regard the Abberly Breccias as Uppermost Carboniferous. There certainly was a temporary return from continental to marine conditions when the Magnesian Limestone was formed, and there is, here and there, some slight trace of a break between that rock (or its equivalent) and the base of the Bunter Marl, which comes on next above it in most sections where the Upper and the Lower New Reds occur together, but its significance is small. On the Continent, and especially the Alps and in Sicily, there is a thick series of strata of marine origin which bear the same relation to the British Lower New Red that the marine Devonian Rocks do to the true Old Reds of Britain. Beyond the area that is here specially under consideration, *i.e.* in India, there is even a thicker series of rocks of marine origin, which are abundantly fossiliferous, and which must be paralleled with our Lower New Red. In the South European types of these rocks Ammonites abound, and 17 genera, including 54 species of these cephalopods, have already been described from Sicily. Again, with regard to this important fauna, I need not do more than again emphasise the chronological importance of the facts. Nothing can be clearer than the fact that the nearly barren Lower New Red of Britain is represented elsewhere by strata of marine origin, which are crowded with a varied assemblage of fossils, whose mode of occurrence as surely attests the slow deposition of the thick mass of strata in which they occur as does that of the fossils which occur in the Chalk. Perhaps it may be useful here to refer the reader to Gemellaro’s “Fauna dei calcari con fusulina del fiume Sosio” for information about the Sicilian (or Panormian) beds, and to Waagen’s “Salt Range Fossils” in the *Palæontologica Indica* (1879-88), if fuller information upon this matter is desired.

It may be remarked that the name “Permian” has not here been used in the original sense. This has been done because it appears that there is some doubt, even in Perm itself,

whether a large part of the "Permian" there does not in reality belong to the Trias, and whether part of the remainder is not (as so much else is in Britain that has been described as "Permian") really nothing more than rocks of Carboniferous age stained by infiltration from the Trias. If the word is to be kept in use at all, its employment should be confined to such rocks as the Abberly Breccias and others such as the Unteres Rotheliegendes of Germany, which *conformably succeed*, even if they overlap, the true Upper Coal Measures. Horace Woodward and I swept much of the so-called "Permian" of the Midland Counties into the Carboniferous on our geological map of England and Wales, published in 1887; and our treatment of these rocks has been amply justified by the results of more recent investigations, and is now generally accepted as correct. In other words, the so-called "Permian" of the Midlands is really of Upper Carboniferous age.

I will not repeat here what I have said before about the chronological value of this vast Pre-cretaceous unconformity; but leave the reader to ponder over the facts, and form an estimate, if he can, for himself.

The next great unconformity in the geological series is that at the base of the New Red Rocks, properly so-called. Without a possibility of a doubt this is certainly one of the most strongly-marked in the geological series, and is, indeed, only equalled in magnitude by the great unconformity between the Caledonian Old Red and the older rocks, to be presently referred to again. The Carboniferous Rocks, including the "Permians" of the Salopian type, can be shown to have undergone an enormous amount of disturbance, which was accompanied by faulting on a very large scale, and which was followed by the denudation of some fourteen thousand feet of rocks, long before the oldest member of the Neozoic Rocks (the base of the Lower New Red or Dyas) began to be laid down. Accompanying this vast unconformity is a considerable amount of overlap, as is well evidenced by the photograph reproduced, Plate VIII., Fig. c, which represents the Inferior Oolite lying upon the upturned ends of the Mountain Limestone, at Vallis, near Frome, in Gloucestershire. The full amount of the overlap may be realised by recalling the fact that all the lower part of the Jurassic Rocks, all the Rhætic strata, all the Upper New Red or Trias, and all the Lower or Dyas are wanting here. Hence these Carboniferous rocks did not begin to be covered as we find them at Vallis until the completion of the long chain of events to which reference was made in the foregoing paragraphs. In addition to that there is to be taken into account also the time required for the disturbance of the Carboniferous

Trans. Geol. Soc. Edin., Vol. VIII., Plate VIII.

Fig. c.—Inferior Oolite unconformable upon the Mountain Limestone. Vallis, near Frome, Gloucestershire.

Fig. d.—Mountain Limestone unconformable to Salopian Rocks, near Horton in Ribblesdale, Yorkshire.

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 299

Rocks, and their subsequent upheaval and denudation. It is, of course, well known that none of this commenced until the very close of the Upper Carboniferous Period. I shall refrain here from attempting to make an estimate of the lapse of time implied by this prodigious unconformity. It will probably suffice for the object in view if I add to the statement just now made regarding the thickness of rock removed, that there was time for almost a complete change in both the flora and the fauna. Hence many will be disposed to agree with those who already think as I do upon such matters, that the real base of the Neozoic Rocks coincides with the base of the Lower New Red (the so-called "Permian"). It is perfectly true that some Deuterozoic types of Invertebrata did linger on until the close of Tyrolian times, as is abundantly evidenced by the Carboniferous types of fossils which are found in the St Cassian limestones; but the broad biological features of the fossils occurring on all the horizons of the marine equivalents of the Lower New Red, from the base of the Dyas upwards, links them on, in an unmistakable manner, to the Neozoic Rocks, as Edward Forbes and others have before pointed out.

Part of the great gap just referred to may be filled in by some rocks which are regarded as of "Permo-Carboniferous" age on the Continent, and possibly also by some of the anomalous rocks met with on this horizon in Shropshire and elsewhere. Part of the gap may also be filled in by the Sicilian rocks referred to above. I may remark, in this connection, that there is much to be said in favour of the view that the Unteres Rotheliegendes of Germany also pertains to this horizon, and is not the equivalent of any part of the true Dyas.

The next unconformity which calls for remark is one regarding which some difference of opinion yet exists. So far as the quantity of rock removed is concerned, it is certainly hardly worth mentioning in the present connection. The break referred to is that between the Upper Carboniferous Rocks and the Lower. Regarding the physical break I will not do more than remark that the base of the Millstone Grit in the North of England seems to me to lie on very different geological horizons in the country around Clitheroe from what it does at various places to the north and north-east of that district. We may know more about this ere long. Messrs Hinde and Fox have shown that an unconformity exists also in Devonshire between the Upper Carboniferous and the Lower (*Q.J.G.S.*, li. p. 609); and Messrs Lapworth and Watts, *Geol. Birmingham District, Proc. Geol. Association*, 1898, p. 370, state that the Coal Measures of the Clee Hills rest unconformably upon the Carboniferous Limestone. But whatever doubt there can be

regarding that point, there can be none whatever regarding the palæontological break on that horizon. This idea of a break between the Upper Carboniferous Rocks and the Lower has been confirmed and strengthened by Dr Traquair's valuable researches amongst the fossil fishes occurring in these rocks, and also by the equally important researches made by Mr Kidston in connection with the fossil plants. Both of these authors have furnished us with lists of organisms, by means of which we are now enabled to determine whether any given set of Carboniferous Rocks pertains to the Upper Division or the Lower. We may look forward with confidence to being able, by the aid of the plant remains, or of the fishes, to "zone" these formations even into various sub-divisions. That we have not yet quite reached that point is, I think, evidenced by the fact that much the same flora is found to characterise beds even low down in the Millstone Grit as elsewhere occurs in the Lower or even the Middle Coal Measures. The late Mr William Gunn and I identified the Brockwell Seam of the Newcastle Coalfield with a coal seam that we and others had mapped right across North-West Yorkshire from the Craven area to the edge of the Newcastle Coalfield. This Brockwell Seam was proved by field evidence which does not, to my mind, admit of any other interpretation, to belong to the upper part of the lowest of the four sub-divisions of the Millstone Grit of the Lancashire Coalfield. Yet the general facies of the plants associated with the Brockwell Coal in the Newcastle Coalfield is practically identical with that which is elsewhere found at a much higher geological horizon in the Upper Carboniferous areas of the Midland Counties.

There are several anomalous features connected with this possible unconformity between the local base of the Upper Carboniferous Rocks and the local top of the Lower. I have held for many years (long before Dr Hinde's papers appeared) that there are higher beds of the Yoredale Rocks left about Clitheroe than remain in the country to the north of that town; and, again, in the country near Skipton, the base of the Upper Carboniferous Rocks appears to lie indifferently upon various horizons much lower in the Yoredale Rocks. It is difficult to understand these features unless they coincide with an unconformity. I think that the facts just referred to can be readily explained if we assume that there was considerable upheaval of the newly formed Lower Carboniferous Rocks at the close of the Yoredale Period, and that a temporary return to arid climatal conditions ensued. This would account for the fact that arkoses are found at the base of the Upper Carboniferous Rocks, as well as for the abrupt and complete change

FIG. 4.—SECTION ACROSS THE MENDIP HILLS. (Scale one inch to a mile.)—From Woodward's *Geology of England and Wales*.

h, Lower Lias; *g*, Rhætic Beds; *f*, New Red Marl and Dolomitic Breccia; *e*, Coal Measures; *d*, Millstone Grit; *c* and *b*, Lower Carboniferous Rocks; *a*, Upper Old Red Sandstone.

FIG. 5.—SECTION THROUGH INGLEBORO, ACROSS THE CRAVEN FAULTS. (J. G. Goodchild, 1887.)
From Woodward's *Geology of England and Wales*.

1, Ancient Sediments, possibly Longmyndian; 1*b*, Bala; 2, Mountain Limestone; 3, Yoredale Rocks; 4, Millstone Grit; 5, Coal Measures, covered unconformably by (6) the New Red. (See also Plate VIII, Fig. *d*.)

in the higher forms of animal life, also for the local effacement of the older flora, and its subsequent replacement by one of a different kind when the former order of deposition was renewed. That explanation of a temporary reversal of terrestrial movements might also serve partly to explain the anomalous attenuation of the Carboniferous Rocks in general as they are followed from east to west nearly all through England, Wales, and Scotland. One of the most remarkable instances of the effects of this attenuation is to be found in connection with the Whitehaven Coalfield. The reader who desires to form some idea of the nature and extent of this attenuation (which may be accompanied also by the unconformity at present under consideration) will find it referred to, and illustrated by comparative sections, in the *Transactions of the Geological Society of Glasgow*, vol. xii., No. 2, pp. 17-39 (1902).

Returning to the palæontological evidence, we find that the invertebrate fossils of marine origin, as well as those of an estuarine facies, remain practically without change from the bottom of the Carboniferous System to its top. There are some few—but very few—exceptions to this general rule. With the fishes, and also with the plants, the case is very different, as the following short lists will serve to show. Thanks to the kindness of Dr Traquair, I am enabled to give two lists here of the most marked species of fish which are respectively characteristic of the Lower Carboniferous Rocks and the Upper. These are as follows:—

UPPER CARBONIFEROUS FISHES. — *Gyracanthus formosus*, *Pleuracanthus lævissimus*, *Strepsodus sauroides*, *Megalichthys hibberti*, *Cœlacanthus elegans*, *Elonichthys egertoni*, *Platysomus parvulus*.

LOWER CARBONIFEROUS FISHES. — (a) Marine: *Cladodus mirabilis*, *Cochliodus contortus*, *Psammodus porosus*, *Ctenacanthus tenuistriatus*; (b) estuarine: *Gyracanthus nobilis*, *Rhizodus hibberti*, *Megalichthys laticeps*, *Elonichthys robisoni*, *Eurynotus crenatus*.

From the valuable lists published by Mr Kidston, my colleagues Messrs Macconochie and Tait have drawn up for me the following lists of fossil plants which are of common occurrence, and are at the same time characteristic of their respective horizons:—

UPPER CARBONIFEROUS.—*Pecopteris arborescens*, *Alethopteris serlii*, *Sphenopteris trifoliolata*, *S. obtusiloba*, *Neuropteris scheuchzeri*, *N. gigantea*, *N. heterophylla*, *Mariopteris muricata*, *Alethopteris lonchitica*, *Calamites suckovii*, *C. cistii*, *Sphenophyllum cuneifolium*, *Annularia sphenophylloides*, *A. radiata*, *Lepidodendron aculeatum*, *Cordaites principalis*.

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 303

LOWER CARBONIFEROUS.—*Calymmatotheca affinis*, *Sphenopteris elegans*, *Rhacopteris inæquilatera*, *Alcicornopteris convoluta*, *Asterocalamites scrobiculatus*, *Lepidodendron veltheimi*, *Cardiopteris polymorpha*, *Lepidophloios scoticus*, *Sigillaria taylori*, *Sphenophyllum tenerrimum*, *Araucarioxylon (Pitys) withami*, *Spirophyton cauda-galli*.

Between the Carboniferous Rocks and the Upper Old Red there also seems to be a local break, which does not, however, appear to be of more than trifling extent anywhere. In some cases the nature of this break is such that it can be readily explained by assuming that the deposition of the marine strata of the Carboniferous Rocks took place against an uneven shore formed by the old desert sands and torrent conglomerates of the older formation, and is thus more of the nature of an overlap. The palæontological break, however, is much more strongly marked than the physical, as one might expect to find would be the case, considering the very different conditions under which these two sets of rocks were respectively formed. On the strength of the palæontological evidence, I now entirely agree with Dr Traquair that the Upper Old Red ought never to have been bracketed with the Carboniferous Rocks. Time must have had quite as much to do with the change of the fauna from the one characteristic of the Upper Old Red to that prevailing in the Carboniferous Rocks, as must the change of physical conditions just referred to.

We can obtain a better general view of the great length of time represented by the Old Red Sandstones and the contemporary marine equivalents if their noteworthy fossils are stated altogether, so as to bring the whole into view at one glance, which will be done further on.

At the base of the Upper Old Red Sandstone occurs another one of the great unconformities. One or more of the older divisions of the Old Red Sandstones has been disturbed, faulted, and denuded to the extent of many thousands of feet, before the Upper Old Red was laid down upon their denuded edges.

Since this Address was delivered I have summarised the leading facts relating to this point in the December number of the *Geol. Mag.* for 1904, and need not repeat on this occasion what has been stated there. But it may be well to state, as a further illustration of the great chronological break between the Upper Old Red and the older division of the Deuterozoic Rocks, that the Upper Old Red locally contains abundant fragments of the Caledonian Old Red granites, which appear to have been formed at great depths below the surface, in connection with the volcanoes from which the lavas found their way into their present position. Furthermore, the Upper

Old Red also contains derived specimens of agates and jaspers which have certainly come from the andesite lavas of the Caledonian Old Red. The original formation of these alone required a vast interval of time, as Bischoff has estimated that the time required for the formation of a pound weight of these minerals under the circumstances could not have been less than 1,296,000 years.

To illustrate the physical relation of the Upper Old Red to the rocks older in the series, two process blocks from photographs are given here. (Plate IX.) Fig. *c*, shows the Upper Old Red of the Siccar Point lying unconformably upon the Gala Valentian) Rocks; Fig. *d* represents the Cornstones lying upon highly metamorphosed schists belonging to the Southern Highland Metamorphic Series on the north shore of Arran, a little to the east of Loch Ranza. For the photograph from which the latter is printed I am indebted to the courtesy of a geologist who does not wish his name to appear.

Below this extensive unconformity at the base of the Upper Old Red occur both the (newer) Orcadian Old Red and the (older) Caledonian Old Red, two formations whose aggregate thickness cannot well be less than thirty thousand feet, and may be considerably more than that. The palæontological evidence, afforded chiefly by fossil fish (for our best knowledge of which we are indebted chiefly to Dr Traquair), confirms the belief suggested by the great thickness of the strata that the rocks represent a vast period of time. More definite statements than such as that cannot be given in the present state of our knowledge. But we can be quite certain of the fact that, while these successive Old Reds were being laid down under continental conditions in one part of Britain, the marine type, represented by the Devonian Rocks, was being deposited in another. I need not dwell at any length upon this episode, but may simply remind the reader that both the character and the thickness of these Devonian Rocks concur with the palæontological evidence in pointing to a vast interval of time. I do not feel quite sure that a true unconformity may not exist between the Upper Old Red of the south-western counties and the true Devonian Rocks of those parts.

In the following lists the noteworthy and zonal fishes of the Old Reds, revised by Dr Traquair, are given in one column, and the zonal forms of the marine Devonian Rocks in another. I specially wish to call the reader's attention to this conjoined evidence relating to the chronological value of the gap between the Upper Old Red and the Silurian Rocks, because even yet there seems to be a widespread misconception regarding it.

Trans. Geol. Soc. Edin., Vol. VIII., Plate IX.

Fig. e.—Upper Old Red Conglomerate unconformable upon
Valentian Rocks, Siccar Point.

Fig. f.—Cornstones (? Upper Old Red) on Highland Schists, near Loch Ranza, Arran.

FIGS. 6, 7, AND 8.—SECTIONS ILLUSTRATING THE RELATION OF THE LOWER CARBONIFEROUS ROCKS AND THE UPPER OLD RED SANDSTONE TO THE SILURIAN ROCKS ON THE BERWICKSHIRE COAST NEAR THE SICCAR POINT.

FIG. 6.

FIG. 7.

FIG. 8.

Marine fossils employed as zonal indices in the Devonian Formation :—

(3) UPPER DEVONIAN.—*Phacops latifrons*, *Ph. rugosa*, *Ph. granulata*, *Entomis serrato-striata*, *Goniatites linearis*, *G. subsulcatus*, *G. intumescens*, *G. bronni*, *G. multilobatus*, etc., *Bactrites elegans*, and other species, *Clymenia undulata*, *C. lævigata*, *C. striata*, etc., *Cyrtoceras ornatum*, *C. nodosum*, etc., *Rhynchonella cuboides*, *Spirifera verneuilli*, *S. disjuncta*, etc., *Orthis interlineata*.

(2) MIDDLE DEVONIAN.—*Bronteus flabellifer*, *B. speciosus*, etc., *Harpes macrocephalus*, *Goniatites latiseptatus*, *G. gracilis*, *G. subarcuatus*, *G. occultus*, etc., *Bactrites carinatus*, *schlotheimi*, etc., *Phacops schlotheimi*, *Megalodon cucullatum*, *Uncites gryphus*, *Atrypa desquamata*, *Spirifera cultrijugatus*, *Stringocephalus burtini*, *Cupressocrinus crassus*, *Calceola sandalina*, *Cyrtina heteroclita*, *Cardiola retrostriata*, *Stromatopora concentrica*, *G. placenta*, etc., *Favosites polymorpha*, etc.

(1) LOWER DEVONIAN.—*Pleurodictyum problematicum*, *Homalonotus armatus*, *H. ornatus*, and many other spinose species of the genus, *Phacops cephalotes*, *Ph. ferdinandi*, *Ph. laciniatus*, etc., *Rensselaeria strigiceps*, *Spirifera primævus*, *Sp. lævicosta*, *Sp. canalifera*, etc., *Strophomena laticosta*, *Ctenocrinus typus*, and other fossils.

Fossil fishes which characterise the three larger divisions of the Old Red Sandstones :—

(3) UPPER OLD RED SANDSTONE.—The whole of the genera *Holoptychius*, *Asterolepis*, *Bothriolepis*, *Phaneropleuron*, and others.

(2) ORCADIAN OLD RED.—*C. Tristichopterus alatus*, *Dipterus macropterus*, *Microbrachius dicki*; *B. Coccosteus minor*, *Mesacanthus peachi*, *Thursius macrolepidotus* and *Th. pholidotus*; *A. Diplacanthus striatus*, *Mesacanthus pussillus*, *Cheiracanthus latus*, *Ch. purchisoni*, *Osteolepis microlepidota*, *Glyptolepis leptoptera*, *Pterichthys milleri*, *Pt. productus*, *Osteolepis macrolepidota*, *Cheirolepis trailli*.

(1) CALEDONIAN OLD RED (not yet definitely divided into palæontological zones).—*Mesacanthus mitchelli*, *Ischnacanthus gracilis*, *Climacodus scutiger*, *C. uncinatus*, *C. reticulatus*, *Parexus recurvus*, *P. falcatus*, *Euthacanthus mitchelli*, *E. elegans*, *E. gracilis*, *E. curtus*, *Cephalaspis pagei*, *C. asper*, *C. lornensis*, *Thelodus pagei*, *Pteraspis mitchelli*, and some few others.

With these occur Arthropods, such as *Kampecaris*, *Archidesmus*, and various Eurypterids, such as *Pterygotus anglicus*, *Stylonurus ensiformis*, and others.

With these it may be useful to compare the presumedly-marine types of fishes such as *Drepanaspis*, and its associates,

which Dr Traquair has figured and described from the Lower Devonian phyllites of Gemünden. (See *Trans. Roy. Soc., Edin.*, Vol. XL. Part iv., and Vol. XLI. Part ii.)

In parts of Wales the Upper Ludlow Rocks graduate into the base of the lowest of the Old Red Sandstones of those parts. In other words, the geological records there include some of the strata which were formed at the time when the marine conditions which prevailed throughout the Silurian Period were slowly giving place to those of a continental type. In Lanarkshire, and some parts adjoining, the remains of similar strata are still left, and these have been brought into very prominent notice of late years on account of the occurrence in them of some very remarkable early types of fossil fishes. The highest beds of the Ludlow types of strata alternate with other petrographical types which are practically identical with those occurring in the Old Red Sandstones. Hence these Lanarkian Rocks were originally described as Lower Old Red. Nobody ever questioned their petrographical affinity with the true Silurian Rocks, and yet, at the same time, it was generally recognised that they must belong to a higher horizon. Perhaps the band of conglomerate which lies not far below the Green Mudstones of these Lanarkian Rocks may coincide with a small break. But in the absence of proof to the contrary the Lanarkian Rocks must be linked with the Silurians.

I have referred to these Lanarkian Rocks in some little detail because they seem to me to be the basal remnant of a formation which has nearly all disappeared; and also because the field evidence is quite clear that the principal disturbances which have affected the Silurian Rocks were post-Lanarkian in date, and were ended long before the succeeding Caledonian Old Red began to be laid down. As a matter of fact, one of the most powerful unconformities in the whole of the geological series occurs between the Lanarkian Rocks and the base of the Caledonian Old Red. This latter oversteps every geological formation older than itself, from the highest surviving remnant of the Lanarkian Rocks down to rocks which may be of Archæan age. What the chronological value of that enormous hiatus may be we have at present no means of learning. So far as the palæontological evidence is concerned, we can only say that there is a considerable difference in the character of the organic remains which occur respectively above and below the plane of the unconformity. We must bear in mind the important fact that not only was very great thickness of strata removed in the interval between the Lanarkian and the Caledonian Old Red; but also that the pre-Caledonian strata had been thrown into their present highly-

convoluted state, and that they had been cleaved, and otherwise altered in petrographical character, before the very oldest beds of the Caledonian Old Red began to be deposited.

So far as the time required for only the deposition of the Silurian Rocks, the palæontological evidence affords us some little insight. Leaving the other fossils out of account, and taking, as it were, only one term for comparison, we might notice the graptolites, from the highest, which ranges to the top of the Salopian (Wenlock-Ludlow in part) division, down to the base of the Valentians or May Hill Beds. The list is taken partly from Miss Wood's papers, partly from information given me by my colleague, Mr Macconochie. Miss Wood gives as the zonal forms of the Lower Ludlow (5) *Monograptus leintwardinensis*; (4) *M. tumescens*; (3) *M. scanicus*; (2) *M. nilsoni* and *M. ræmeri*; (1) *M. vulgaris*. The same writer gives as the zonal form of the Wenlock Rocks (6) *Cyrtograptus lundgreni*; (5) *C. rigidus*; (4) *C. linnarsoni*; (3) *C. symmetricus*; (2) *Monograptus riccartonensis*; and (1) *Cyrtograptus murchisoni*. The zonal graptolites of the Valentians are:—(2) *Monograptus crispus*, *exiguus*, and *turriculatus*; (1) *Rastrites maximus*, *Monograptus spinigerus*, *distans*, *Climacograptus normalis*, and *Petalograptus folium*; *Monograptus clingani*, *Petalograptus cometa*, *Monograptus crenularis*, *Rastrites peregrinus*, and *R. hybridus*; *Monograptus gregarius*, *fimbriatus*, *convolutus*, *argenteus*, and *triangulatus*; *Diplograptus vesiculosus*, *Monograptus cyphus*, and *M. tenuis*; *Diplograptus acuminatus*, *Dimorphograptus confertus*, *D. elongatus*, and *D. swanstoni*.

At several localities in Britain the Silurian Rocks appear to lie quite conformably upon the Ordovician Rocks. Elsewhere an unconformity, varying in extent in different parts, separates the two formations. In the neighbourhood of the Longmynd, for example, the base of the Silurians lies (without any overlap worth mentioning) indifferently across the edges of the Ordovician Rocks, the Cambrians, and a vast thickness of rocks of Pre-Cambrian age. The aggregate thickness of the older rocks thus overstepped (without overlap) by the Silurian Rocks of that part cannot well be less than twenty-five thousand feet, and it may, indeed, be more even than that vast amount. What matters it that apparent conformity exists elsewhere between the Silurian and the Ordovician Rocks if this enormous gap, requiring untold ages for its accomplishment, exists between the two at any point? The philosophical geologist will not fail to perceive in that great unconformity additional evidence of the fact that the existing strata, thick as they are, and long as they must have taken to form, represent but a small part of the great period of time of which the geological record has to tell.

FIG. 9.—GENERALISED SECTION ACROSS THE CHEVIOT HILLS AND THE WESTERN BORDER OF NOTHUMBERLAND. (By J. G. Goodchild, 1887.)
From Woodward's *Geology of England and Wales*.

To illustrate the unconformities above, and below, the Caledonian Old Red of the Cheviot area.

a, Silurian Rocks (Wenlock); *b*, Caledonian Old Red, lying with a violent unconformity upon *a*; *c*, Upper Old Red, unconformable to *b* and *a*;
c', Kelso Traps interbedded in the upper part of *c*; *d* and *e*, Lower Carboniferous Rocks (*e* given as the Yoredale Rocks in 1887).

FIG. 10.—SECTION ON THE EASTERN SLOPE OF THE LONGMYND, NEAR CHURCH STRETTON, SHROPSHIRE.—From Woodward's *Geology of England and Wales*.
To illustrate the great Unconformity at the base of the Silurian Rocks.

a and *b*, Sedimentary Rocks near the base of the Longmyndians (Pre-Cambrian); *e*, *f*, *g*, *h*, Silurian Rocks lying unconformably upon *a* and *b*.
The whole of both the Cambrian Rocks and the Ordovician are absent below *e*.

It happens in the case of the pre-Silurian unconformity, whether considered in the Longmynd or elsewhere, that there is some danger of referring the date of the removal of the whole of the missing rock to the period which followed the close of Ordovician times and preceded that when the basement beds of the Silurian Rocks began to be laid down; whereas only part of the missing rock may have been denuded then, and the remainder may represent the aggregate of more than one or two periods of denudation dating from earlier times. Thus in some localities there appears to be a physical break (as there certainly is in general a palæontological one), at the base of the Bala Rocks; and the very strongly marked palæontological break at the bottom of the Arenig Rocks is also suggestive of a corresponding gap in the stratigraphy on that horizon. Hence, it is not an easy matter to decide how to allocate the several component unconformities which go to make up the grand total referred to. It must be, however, sufficiently evident in any case, that collectively, and quite apart from any collateral evidence, they betoken a vast lapse of time, of the actual chronological extent of which, in the present state of our knowledge, we have no means of fixing an exact estimate. But if we consider even that one section of the palæontological evidence which relates to the succession of the graptolites, that, in itself, should afford an adequate idea of the enormous length of time required. Accordingly, lists of the chief zonal graptolites of the Ordovician Rocks, for which I am chiefly indebted again to Mr Macconochie, are given as follows:—

UPPER BALA.—(5) *Dicellograptus anceps*, *D. truncatus*, and *Diplograptus foliaceus*; (4) *Dicellograptus complanatus*, *Leptograptus flaccidus*, *Diplograptus socialis*, *Amphigraptus divergens*; (3) *Climacograptus tubuliferus*; (2) *Pleurograptus linearis*, *Diplograptus quadrimucronatus*, *Dicellograptus forchammeri*, *D. clingani*, *D. caduceus*, *Dicranograptus ramosus*, *Climacograptus caudatus*; (1) *Cryptograptus tricornis*, *Diplograptus rugosus*, *Lasiograptus harknessi*, *Climacograptus scharenbergi*, *C. wilsoni*.

LOWER BALA (or Upper Llandeilo of Lapworth).—(3) *Climacograptus bicornis*, *C. peltifer*, *Hallograptus mucronatus*, *Thamnograptus typus*, *Dicranograptus rectus*, *Glossograptus hincksii*, *Didymograptus superstes*, *Cænograptus gracilis*, *C. pertenuis*, *Dicellograptus sextans*, *D. zic-zac*, *D. divaricatus*, *Diplograptus mucronatus*, *D. bimucronatus*.

As remarked above, in some places there is good evidence of a physical break (as well as a palæontological one) at the base of the Bala Rocks, as here defined. But the rocks which appear to me to form the downward continuation of what has

ON UNCONFORMITIES AND PALÆONTOLOGICAL BREAKS. 311

been classed as Lower Bala in the above lists, are those which I named the Milburn Beds, which are exposed near the village of that name on the north-eastern edge of Westmoreland. From these rocks a large number of graptolites has been obtained by my wife and my son Wilbert. Messrs Marr and Nicholson have also collected extensively from these rocks, and it was chiefly from specimens obtained by these geologists that Miss Elles has identified the following species of graptolites, most, if not all of which may be regarded as characteristic :—

B. MILBURN BEDS (Lower Llandeilo or Llanvirn, in part).—*Trigonograptus lanceolatus*, *Glossograptus fimbriatus*, *Azyograptus celebs*, *Didymograptus bifidus*, *D. fasciculatus*, *D. murchisoni*. With these occur the following trilobites:—*Agnostus morei*, species of *Placoparia*, *Aeglina binodosa*, and some other species of that genus.

A. ARENIG BEDS.—Characterised by the occurrence of the genera *Tetragraptus*, *Phyllograptus*, *Dichograptus*, and others. Below this horizon graptolites are no longer available as zonal fossils, and the scale employed in chronological measurement is one in which trilobites figure most prominently. It may be remarked at this point that the zoological position of the fossils used as zonal forms must necessarily vary in accordance with the nature of the sediments amongst which those fossils are entombed, and this was regulated in the first place by the environment of the living organisms. Probably the graptolitic phase affords the most trustworthy terms of comparison because the fine textured black mudstones in which the graptolites usually occur were formed with extreme slowness, and under uniformity of bottom conditions over great extents of the sea floor. As an illustration of the variation in the character of the fossils under different conditions of deposit, reference may be made to the two groups of strata just mentioned, *i.e.* the Llanvirn or Milburn Rocks and the Arenig Rocks. In North Westmoreland the prevailing type of deposit in the Milburn Rocks consists of alternations of subordinate bands of greywacke containing a variable admixture of pyroclastic material, with predominant thinly-bedded mudstones, which yield the fauna referred to. These rocks must be several thousand feet (about seven thousand, perhaps) in total thickness. At no great distance to the north-west the Milburn Rocks are certainly represented by the deep-sea Radiolarian Cherts, which appear to floor most of the Southern Uplands of Scotland, because these rocks certainly overlie others containing the graptolite fauna proper to the Arenig or Skidda Slate series, which forms the next older division of the geological series. Then,

again, the true Skidda¹ Slates, which, as just now remarked, belong to an older part of the geological series, resemble the Milburn Beds petrographically (but contain little or no volcanic material), and are represented in the Southern Uplands by the Ballantrae Volcanic Series. Finally, the great group of greywackes and argillites which forms what Clifton Ward termed the Grasmoor Grits, in Cumberland, and underlies the true Skidda Slates, appears to me to be partly the equivalent in time of the Durness Limestone of Skye, etc. These considerations must lead geologists sooner or later to the conclusion that lists of zonal fossils, if they are to be of real value over a large area, must be drawn up on a much wider basis than we have been until quite recently accustomed to adopt. We must employ several scales for the purpose, each relating to some particular petrographical type of deposit. These "scales" might well be given side by side when one is dealing with a particular group of rocks. For example, in dealing with the chief zonal forms of the Cambrian Rocks geologists have rightly agreed to make use of the trilobites almost exclusively. But trilobites could also be employed almost as advantageously as graptolites when we are dealing with the Ordovician and Silurian Rocks, or even with the Deuterozoic Rocks above them; and a list drawn up on such a basis might well have been given here when we are dealing with the fauna of the Cambrian Rocks in relation to time, had space permitted of this being done.

With a view to bringing the time-value of the Cambrian Period prominently before the eye, the following list of Cambrian zonal fossils, chiefly Trilobites, and mostly from Scandinavian localities, is here given:—

TREMADOC.—*Angelina* (genus), *Niobe* (*Asaphellus*) *homfrayi*, *Ceratopyge forficula*, together with *Bryograptus*.

OLENIDIAN.—(7) *Acerocare ecorne* (with *Dictyograptus flabelliformis*); (6) *Cyclognathus micropygus*, with *Sphærophthalmus alatus*, *Agnostus trisectus*, and *Ctenopyge pecten*; (5) *Peltura scarabæoides*, *Leptoplastus stenotus*, *L. ornatus*, *Eurycare angustatum*, *E. camuricorne*, *E. latum*, etc.; (4) *Parabolina spinulosa*, with *Orthis lenticularis*; (3) *Beyrichia angelini*, with *Agnostus cyclopyge*, *Ceratopyge*, etc.; (2) *Olenus truncatus*; (1) *Olenus gibbosus*, *O. cataractes*, *O. truncatus*, and *Agnostus pisiformis*.

PARADOXIDIAN (chiefly after Linnarson).—(6) *Agnostus lævigatus*; (5) *Paradoxides forchammeri*, with *Hyolithes tenuistriatus*; (4) *Paradoxides elandicus*; (3) *P. davidis*; (2) *P. tessini*, *P. hicksii*, with *Conocoryphe exulans*; (1) *P. kjerulfi*, with *Ellipsocephalus* and *Arionellus*.

¹ Usually spelt with a final w.

The Section here given is partly adapted from one originally devised by Professor T. M'K. Hughes, which was used to illustrate a paper read before the Cambridge Philosophical Society on May 5th, 1879, "On the Relation of the Appearance and Duration of the various Forms of Life upon the Earth to the Breaks in the Continuity of the Sedimentary Strata" (*Proc. Camb. Phil. Soc.*, vol. iii. pt. vi. pp. 246-258).

OLENELLUS BEDS.—All the genera and species of the *Olenellus* group.

Along with these Cambrian Trilobites there occur several other groups of fossils which are apparently restricted to rocks of this age. Amongst these may be mentioned such Spongida as *Archæocyathus*; and such Brachiopod genera as *Acrotreta*, *Obolella*, *Kutorgina*, *Acrothele*, and others. Together with these fossils there occur some organisms which bear a superficial resemblance to the modern Pteropods (a group, by the way, which did not make its first appearance until late Tertiary times). These include *Hyolithes*, *Hyolithellus*, *Salterella*, and others, and to these may be added *Stenotheca*.

I have not taken here into account the remarkable Cephalopod fauna of the Durness Limestone, as we must await the publication of the forthcoming Geological Survey Memoir dealing with that rock before expressing any opinion as to its exact position in the geological series.

I have now passed in review the facts presented by these two lines of enquiry. They seem to me to corroborate almost every estimate I made in my former Address. That being the case, I do not feel that it is necessary on this occasion to repeat my original estimates. I will simply remark, in conclusion, that if I felt inclined to modify those estimates at all, the change would certainly be in the direction of increasing the estimate rather than in that of diminishing it.