III.—ORIGIN OF THE ARCHÆAN ROCKS.

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IT is somewhat remarkable that, just as physicists are assuring geologists that the latter will have to quicken their forces, so as to bring the geological history of the globe within the definite limits assigned by the physicists themselves, the geologists reply by adding several thousand feet more rock in various parts of the world to the already thick column of sediment, and many would assure us that these 'Archæan' rocks were produced in a manner similar to the fossiliferous rocks, from which they differ in such important particulars.

Various attempts have been made to account for the mode of formation of these Archæan rocks under conditions different from those prevalent in later times, but little notice has been taken of these theories. The two extreme views are perhaps those of Mr. Mallet and Dr. Sterry Hunt; but although these authors attempt to explain the phenomena of regional metamorphism, they give us no clue whatever to many of the other difficulties connected with the Archæan rocks. Some of these difficulties may be here enumerated.

1. The amount of time required to accumulate the great thickness of Archæan rocks, to metamorphose them, and to denude so great a quantity of material as to expose the metamorphosed rock at the surface would be very great, if these rocks were originally deposited as ordinary aqueous sediments. True, according to Mr. Wallace's calculations (*Island Life*, p. 203), the whole thickness of sedimentary rocks could be formed in a time much shorter than that which physicists are disposed to allow us. But even admitting the accuracy of Mr. Wallace's data for estimating the comparative rates of removal of a thickness of material from our continents, and its settlement upon areas receiving sedimentary deposits at the present day, there are many possibilities to be taken into account which might seriously alter his results. If denudation acted more rapidly in past times, deposition on the other hand would probably take place over areas more remote from the land than those to which it is confined at the present time. Again, if we suppose that continents have gradually grown in size, a far smaller amount of land-surface would have been exposed to denudation in past times than at present.

2. The evidence in favour of the permanence of our ocean basins is now very strong, gathered as it is from considerations stratigraphical, palæontological, physical, and founded upon the geographical distribution of life. Mr. Wallace may well say, whilst commenting upon this theory, that Mr. Charles Darwin's argument, framed on the absence of Palæozoic and Secondary rocks upon oceanic islands,¹ "coming in support of the long series of facts of an altogether distinct nature, going to show the permanence of continents, the cumulative effect of the whole must, I think, be admitted to be irresistible" (*Island Life*, p. 98).

¹ See *anti*, Mr. Crosby's article, p. 251.

If this theory be accepted, it raises very serious difficulty in the way of accounting for the Archæan rocks, upon the supposition that they were deposited in the sea. Mr. W. K. Gilbert (*Nature*, vol. xxvii. p. 262) has insisted upon the fact that wherever the Archæan rocks are found, succeeded by newer formations, there is an unconformity between the two. This means that in early Cambrian times, the localities where Archæan rocks are found succeeded by Cambrian rocks (and they are many, and widely distributed) were occupied by land. On the other hand, in Pre-Cambrian times, these areas were occupied by ocean, if the Archæan rocks are oceanic deposits. But since the Archæan rocks are so widely spread over our present continental areas, where was the land, the denudation of which supplied the material for these rocks? It must almost necessarily have occupied the sites of our present oceans, unless we suppose that these land surfaces lay in every case in those areas which are now covered by newer rocks. This goes against the theory of the permanence of the sites of oceans and continents, for in Archæan times the present continental areas were occupied by great oceans (always assuming the oceanic formation of these rocks), and the present oceanic areas by land, whilst at the end of Archæan times, our present continental areas were converted into land.

Objection may be raised that the Archæan rocks were not being formed simultaneously in different areas. If this be so, the occurrence in so many areas of a series of highly altered gneissose and other rocks, succeeded by a less highly altered series of green more or less schistose rocks, is a singular coincidence. Again, it may be objected that newer rocks of different ages were deposited unconformably upon the Archæan rocks, for instance, in Westrogothia, the Fucoid sandstones rest unconformably upon them; in parts of Bohemia, the sandstones below stage *C*, and in other parts the band *D. d* 1a.; whilst in Britain, we find Harlech beds at St. Davids, Lingula flags at Malvern, Arenig rocks at Carnarvon, etc. But this, as shown by Dr. Hicks (*Quart. Journ. Geol. Soc.* vol. xxxi. p. 552), indicates the submergence of successive portions of a sloping Archæan land, rather than successive upheavals of different parts of an Archæan ocean-floor. If the break were not produced in all areas simultaneously, it is exceedingly difficult to account for the entire absence of ordinary unmetamorphosed marine sediments of Archæan age.

3. The theory of the growth of continents by successive additions along their borders, advocated by Dr. Dana in North America, seems with slight modifications to be applicable to the European continent also. The Cambrian and Silurian rocks stretch far eastward into Russia, and are found north as far as Jemtland in Sweden, and above Bergen in Norway, and as far south as Spain and Sardinia, usually as wide-spread marine deposits. In Devonian and Carboniferous times, various ridges of land existed in this ocean, and in Mesozoic times the site of the European continent was occupied by wide Mediterranean Seas, as shown by Mr. Wallace (*Island Life*, p. 87). In Tertiary times, the continent was so far compacted, that it was

occupied by more contracted seas in the early Tertiary times, and by gulfs ramifying through the centre of the continent in still later times.

The unconformities separating different systems show that the growth was not continuous, the continent being sometimes larger at an earlier than at a later period, but in no case are these unconformities spread all over the continent with great discordance of dip and strike, except at the end of Archæan times. This is remarked by Mr. Gilbert in the place alluded to before. The break at the top of the Archæan rocks is not only shown by great discordance of the strata above and below, but is also marked by the immense amount of denudation which took place at the end of Archæan times: this will be considered shortly. Such being the case, if the theory of growth of continents be true for later times, it will not hold good for Archæan times, if those rocks are of marine origin.

It is worthy of notice that the two theories just considered—that of the permanence of the site of ocean basins, and that of the growth of continents—receive much support from the evidence furnished by the newer rocks, but are confronted with serious difficulties by the theory of marine origin of the Archæan rocks.

4. The vast amount of denudation which took place at the end of Archæan times has hardly received the notice it deserves. This denudation is shown to have been very great by distinct kinds of evidence.

Whatever the cause of production of the regional metamorphism of these old rocks, the fact remains that the most altered rocks are extensively penetrated by granitic masses. In Scandinavia the schists are in many places so traversed by granites that it is exceedingly difficult to separate granite from metamorphic rock, and the same may be remarked in Bohemia, and judging from published accounts, in many other areas where Pre-Cambrian rocks occur. In Scotland, the great quantity of pegmatite may be judged from the descriptions in Dr. A. Geikie's *Text Book of Geology*, p. 640. In North America also, granites are abundant, and whether or not these granites produced the metamorphism, they show that *at the time they were intruded, the rocks which they penetrated were at a considerable depth below the surface.* The abundance of these granites in Archæan rocks has been explained by the age of the rocks, and therefore their greater likelihood of being penetrated by granite than newer formations. However, a great deal of this granite is undoubtedly of Archæan age, as shown by the occurrence of granite pebbles in the conglomerates of the Cambrian system, and by the comparative rarity of granites in Cambrian rocks resting immediately upon Archæan rocks, which are very largely penetrated by that rock.

It follows that the denudation at the end of the Archæan times was sufficient to lay bare a great quantity of granite formed at a considerable depth, and that such granite has been more rarely exposed in later times.

The great denudation of the rocks is also shown by the extreme irregularity of the submerged land upon which the Cambrian rocks

were deposited. This irregularity might be due to the inequality of earth-movements at the commencement of Cambrian times, a thing rendered extremely unlikely by the great uniformity of character of many Cambrian deposits over wide areas, and its improbability may also be judged of, by attempting to apply this explanation to two particular cases which may be taken from many others by way of illustration. The first is the mode of occurrence of the Cambrian rocks of North Wales and the East Coast of Ireland, as shown in Fig. 1, which indicates the manner in which the Cambrian deposits overlap one another against the old Pre-Cambrian ridge.

5. Arenig Beds. 4. Tremadoc Slates. 3. Lingula Flags. 2. Harlech Series.
The dotted part indicates shore deposits. Vertical scale much exaggerated, and part W. of Carnarvon much shortened horizontally.

In tracing the Cambrian beds from Llanberis to Carnarvon, a thickness of several thousand feet of rock is found to thin out and disappear in a horizontal distance of about eight miles, as shown by Sir A. Ramsay (*Mem. Geol. Survey*, vol. iii.), and the same thing is seen in tracing the rocks from Ireland towards Carnarvon, only the thinning out here takes place more slowly. The inequality of movement would have to be very great if this distribution of the beds is to be explained in that way, whilst the Llanberis and Irish areas were depressed, the narrow ridge between would be kept continuously above water. A similar change is shown to occur between the Longmynd Hills and the Wellington area, where the Hollybush sandstone rests on the Archæan rocks, and other phenomena of the same nature are found in Sweden. They appear to point to the submergence of great mountain masses sculptured by subaerial denudation, and this would also account for the remarkable character of the boulder conglomerates found in Cambrian beds of different ages, where they rest upon the Archæan rocks, as those described by Dr. A. Geikie in the north of Scotland (cf. "*Geological Sketches at Home and Abroad*"), and by Prof. Lapworth in the Girvan district (*Quart. Journ. Geol. Soc.* vol. xxxviii. p. 537).

The high mountains would give rise to glaciers and Boulder-clays formed upon their flanks; upon the submergence of these tracts, the clays would be re-sorted, and the boulders somewhat rounded. Some such explanation as this is required to account for the great size of the stones in many Cambrian conglomerates of different ages,

in various parts of Europe, and the absence of large pebbles in the basement beds of different age in many other parts of Europe. The large boulder conglomerates would be formed where Boulder-clay was found to supply the pebbles.

Another illustration of the irregularity of the Archæan land-surface is still more difficult to explain by irregular earth-movements, but presents all the appearance of a large submerged valley. This is furnished by the distribution of the stage *C* in Bohemia. The beds of this stage are found at Skrey on the north side of the basin of Lower Palæozoic rocks, and at Ginetz on the south side, and they rapidly die out in an east and west direction at both these places. They rest upon conglomerates and sandstones, whereas in other parts of the basin the conglomerates and sandstones of stage *D* rest upon Archæan rocks, so that a section across this part of the basin before the disturbance of the Cambrian rocks would be somewhat as shown on Figure 2.

The beds of stage *C* extend for a distance of about thirty kilomètres on the north side of the basin, and a little less than this on the south side, and the deposits of *C*, and the underlying sandstones and conglomerates are many hundreds, and probably thousands, of feet in thickness. It seems that here a large valley was submerged in Cambrian times, and that the valley was one of denudation, and not produced by earth movement, for *the direction of the depression is about at right angles to the direction of strike of the Archæan rocks in which it occurs.*

From all these considerations, it would seem to follow that an enormous amount of denudation took place at the end of Archæan times, quite sufficient to bring to the surface great masses of rock which were metamorphosed at a considerable depth below it.

5. An abnormal amount of volcanic activity appears to have occurred during Archæan times. Where the rocks are comparatively unaltered, the volcanic rocks are readily recognizable, as at St. Davids, Bangor, the Wrekin, and other places (*cf.* papers by Messrs. Hicks, Hughes, Bonney, Callaway, and others in the Geological Society's Journal), and it seems to be recognized more and more, that some at least of the highly altered rocks are also of volcanic origin. Professor Bonney, for instance, speaks of certain Cornish hornblende schists as possibly "having been basaltic tuffs with which in chemical composition they would agree fairly well" (Quart. Journ. Geol. Soc. vol. xxxix. p. 19). Mr. Reusch also (Silurfossiler og Pressede Konglomerater i Bergenskifrene) considers that the

gabbros, diorites, dioritic schists, hornblendic schists, and other metamorphic rocks of the Bergen district, are altered tuffs and eruptive rocks. He gives two alternatives as to their age (p. 105), one that they are Silurian, and interstratified with the somewhat altered fossiliferous rocks; the other, that they are inverted anticlinals, with the fossiliferous rocks occurring as synclinals between them. In either case, they seem to give evidence that regionally metamorphosed rocks of similar character to those found in the Archæan systems may be produced by the alteration of possible volcanic rocks. Whilst alluding to this work of Mr. Reusch, it may be further noticed that great interest attaches to the fossils of Silurian age occurring in such highly altered rocks as those described by Mr. Reusch. When we hear of fossils preserved under these circumstances, it is noteworthy that the limestones in the Archæan rocks, which have been examined so carefully, have yielded nothing more satisfactory than the dubious Eozoon. Professor Heddle, in his descriptions of "the County Geognosy and Mineralogy of Scotland" concludes that among the most metamorphic rocks of Sutherland is a series of contemporaneous volcanic sheets.

The occurrence of so much volcanic matter, so widely spread among the Archæan rocks, is difficult to explain, if we suppose that the great bulk of the Archæan rocks was formed under conditions similar to those under which the ordinary fossiliferous rocks were produced.

6. The Archæan rocks present many peculiarities which it is exceedingly difficult to explain, if they be considered as marine deposits, whereas many at any rate of the types found might be produced by the alteration of ordinary pyroclastic rocks. The Cornish rocks do not appear to have yielded to Prof. Bonney's searching microscopic examination any convincing proofs of their marine origin, for in a footnote on p. 19 of the paper referred to above he says, "While examining this hornblendic group I had always present to my mind the possibility that the more massive varieties might be really metamorphic igneous rocks, but I obtained no evidence in favour of this view, and am disposed to regard the group as, at any rate in the main, of sedimentary origin." The cautious way in which Prof. Bonney speaks of them would seem to allow of the possibility that they may be of pyroclastic origin.

Many of the green schistose rocks would appear to be of such a composition as is quite in accordance with their pyroclastic origin, but when we remember the difficulty of distinguishing in some cases a comparatively unaltered pyroclastic rock, from the grits derived from the denudation of such rocks, it will prevent us from laying much stress upon this point. However, if so many Archæan rocks can be proved to be of volcanic origin, it is quite as legitimate to conclude that others also are of volcanic origin, where the original nature is nearly obliterated, as to suppose that these latter are marine sediments, unless we can point to undoubted marine sediments in the Archæan rocks. Once granted that volcanic action was more powerful in Archæan times than in later times, and we admit that

the conditions under which the Archæan rocks were produced were somewhat different from those under which later rocks were produced, and this difference may have been very great. What actual evidence have we, then, of marine or fossiliferous rocks of Archæan age? The cases usually cited are :—

- (i.) Crystalline limestones, some containing Eozoon.
- (ii.) Beds of graphite.
- (iii.) Beds of hæmatite.

As to Eozoon, we know that “doctors disagree,” and it can hardly be brought forward as an argument in favour of the marine origin of the rocks in which it occurs, if other facts are opposed to this. It is unnecessary to quote the numerous authorities who are opposed to the organic nature of this structure.

With regard to the rocks themselves, these facts are worthy of consideration :—The crystalline limestones appear to be mainly lenticular masses of small extent. This is the case in all areas where the writer has had an opportunity of examining them. The presence of these very lenticular patches and the absence of wide-spread beds of limestone would point to this rock not having originated in an Archæan sea, but in some other manner, as by precipitation from calcareous springs, such as are found in most volcanic districts. The graphite also has been appealed to, as proving the former existence of organisms, but we know that graphite is also formed under other circumstances. It is found disseminated as scales, as well as occurring in pockets in the Borrodale beds of the Lake District; it occurs in the same way in Bohemia, not only in apparent or real layers, and pockets, but also disseminated as scales in the gneissose rocks, forming in places actual graphitic gneisses. The hæmatite is supposed by Dr. Sterry Hunt to have been produced by precipitation of iron by vegetable matter; in these same Borrodale beds, we meet with masses of hæmatite, which could hardly have been formed by filtration from rocks above them. Certain white flinty rocks occurring among the green schistose rocks in Bohemia bear a striking resemblance to siliceous sinters, but this may be only superficial.

These rocks, then, need not necessarily have been formed in the sea, as similar rocks are formed on land, in volcanic regions. Furthermore, the different varieties of rock do not occur in the same relative abundance as one would expect, if they were ordinary marine sediments which had been subsequently altered. In all newer systems we find great masses of limestone somewhere or other, *e.g.* the Cambrian limestones of Russia and Eastern Sweden; the Silurian of Russia, Sweden, Bohemia, Niagara, etc.; the Devonian of Devonshire, and the Eifel; the Carboniferous of Western Europe; the New Red of the Alps; the Jurassic and Cretaceous of Western Europe; and the Tertiary of Europe, the Himalayas, etc. In the Archæan rocks, on the other hand, although such large areas are exposed, we never seem to get large masses of limestone, but merely these lenticular patches. A glance at the Geological Survey Map of Anglesey will show the great contrast which these Archæan limestones show to other limestones.

The difficulties above considered are suggested, if the marine origin of the Archæan rocks be adopted; but if they were formed on land, the difficulties disappear, and the feasible way of accumulating such rocks on land is by volcanic action.

The researches of Prof. George Darwin upon the tides, and the geological bearings of his investigations, have been singularly little heeded by geologists, who are apparently content with the proofs that the earliest fossiliferous rocks present the appearance of having been accumulated under tranquil conditions similar to those now obtaining in our oceans, and ignore the fact that the reverse appears to be the case when we examine the Archæan rocks, and that a strict comparison betwixt these and the ordinary rocks cannot be successfully established.

Let us consider the changes which might take place after the separation of the moon.

1. Prof. Darwin, I believe, considers that a scar would be left where the mass which formed the moon separated from the earth, which might still be occupied by part of our oceans; he also says (Proc. Roy. Soc. vol. xxviii. p. 196), that wrinkles running in a general north and south direction might be raised in the earliest stages after separation, by disturbing force, and he points out that the present continents or large wrinkles conform more or less to this law, and adds, "it must be supposed that the general direction of the existing continents has lasted through geological history," a supposition to which the marine origin of the Archæan rocks is, as already explained, opposed.

2. Prof. Ball ("A Glimpse through the Corridors of Time,") considers that the water condensed upon the earth after the separation of the moon's mass. It would occupy the scar left by the separation, and perhaps parts of the depressions, forming somewhat small primæval oceans. The pressure caused by the watery atmosphere before its condensation would be, as Mr. Fisher states in his "Physics of the Earth's Crust," very great; consequently, when this pressure was removed by condensation, there would be removed an obstacle to the outburst of vulcanicity. There would be, therefore, a tendency to volcanic activity of considerable, and perhaps paroxysmal violence. (The occurrence of such paroxysmal eruptions at some period or other in the moon itself is worthy of recollection in connexion with this.) If the outbursts were paroxysmal, the result would be the production rather of pyroclastic rocks than of lavas, and these pyroclastic rocks would not necessarily be coarse because of the violence of the action, for we know that during violent outbursts many of the fragments fall back into the crater, and are thrown out again and again, until at last they are reduced to an exceedingly fine state of division (Cf. Judd, "Volcanoes," p. 174). In this way the fine false-bedding described by Dr. Sorby and more recently by Prof. Bonney as occurring in these rocks might be produced, just as similar false-bedding is found in pyroclastic rocks at the present day, and in many ancient volcanoes. A peculiarity of the Archæan rocks noticed by Dr. A. Geikie (Text-Book of Geology,

p. 637), viz. that "the rocks have a general stratified structure, but the individual beds often present great irregularities of thickness, being specially prone to lenticular development," is quite explicable if we suppose they were volcanic products, but otherwise is only accounted for on the supposition that they were all shallow-water deposits, which seems somewhat improbable.

3. The rapid accumulation of great masses of volcanic matter would cause the first formed outpourings to become deeply buried, so as to be brought within the influence of metamorphic action, whether produced by heat, pressure, and water, or by intrusion of granite and other plutonic rocks, or by both causes. The metamorphosed rock becoming denser, would contract, and cause puckerings.

4. At first, as volcanic activity was more violent, denudation could not take place so rapidly as accumulation, but as the volcanic forces died out, the intensified denuding forces supposed by Prof. Darwin to have been brought into play would remove much of the accumulated material, lay bare wide areas of the once deeply buried rocks which had become greatly metamorphosed, leave here and there some rock only partially metamorphosed, but remove all or nearly all the unaltered rocks at the top, and would carve out the system of hill and valley described in a former part of the paper. On these hills glaciers might be formed.

5. As this great denudation removed large masses of rock, it would again relieve the pressure, and some of the quartz felsites intruded in the newer Archæan rocks might be thus permitted to force their way up, and perhaps give rise to those comparatively unaltered rhyolitic rocks and ashes which occur at the summit of the Archæan rocks in some places.

6. We know that volcanic areas have a tendency to subside, on the dying out of volcanic activity. For this reason (and also because the rapidly denuded materials of the land would be washed into the scar left by the moon's separation, and tend to fill this up), the seas would gradually encroach upon these irregular Archæan lands, and so the Cambrian rocks would commence at different times to be formed against different levels of this subsiding land surface, generally being formed sooner in the west of Europe than in the east, as explained by Dr. Hicks in a paper already referred to, but the oldest of these rocks in Europe being always of comparatively local distribution, because they were deposited in wide submerged valleys, whilst the intermediate mountain ridges received no deposits at that time.

The terrestrial and volcanic origin of the Archæan rocks, if it can be maintained, would dispose of most or all of the difficulties hitherto discussed. The great difficulty in the way of the ordinary metamorphic theory of these rocks, namely, the wide-spread occurrence of regional metamorphism in Archæan times, and its rarity in later times, is accounted for, as similar metamorphism would be going on at later periods, but the exceptional violence of denudation, and its long continuance, would explain the exposure at the surface of so much Archæan rock altered at a great depth. This exceptional

wide-spread denudation no longer occurs with such violence, but great denudation for long periods still goes on in mountain chains, and there we should expect to find regionally metamorphosed rocks of later age.

One or two objections to the view of the volcanic origin of the Archæan rocks may be here discussed. Of course, any convincing proofs of the marine origin of beds of this age would be fatal to their terrestrial and volcanic origin in the manner above suggested. At the same time, it may be pointed out that local aqueous deposits might be formed in lakes upon the land, or that moxas poured out from craters would form layers of argillaceous sediment, which would resemble marine deposits. Such an argillaceous band has been mentioned by Prof. Bonney as occurring amongst the quartz felsites at the foot of Llanberis lake, but it is very thin.

A very great difficulty is that connected with the evolution of life. A large part of the earth would be absolutely unfitted for life when the volcanic rocks were being accumulated, consequently the rich variety of forms in the Harlech rocks of St. Davids is very perplexing. It may be remarked, however, that according to the views above advanced, great deposits of sediment would be formed in the ocean basins long before the present continental areas had become submerged, and there would be a violent struggle for existence in these oceans, owing to the abnormal rate of physical change; these rocks, if thus formed, are for ever lost to us, and we can never hope to find traces of the earliest organisms, buried beneath our present oceans. It by no means follows that we need despair of finding organisms older than those of the Harlech rocks of St. Davids. It has been pointed out with what great irregularity the earliest Cambrian sediments were deposited, so that somewhere or other in our present Continental areas, rocks of Cambrian age, and earlier than the Harlech beds of St. Davids, may be discovered. The great thickness of rocks in North Wales and the Longmynd Hills, as compared with those of St. Davids, is doubtless partly due to their shallow-water character, but perhaps also to the lowest rocks in these areas having been formed before the St. Davids area was submerged, and where such rocks have not had their organisms obliterated by subsequent cleavage, we may hope to find less differentiated forms than those of the Caerfai rocks of St. Davids.

Again, there are many other difficulties besides the one here raised, against the acceptance in full of the theory of natural selection, which have been noted by various palæontologists, among whom may be mentioned Barrande, Carruthers, and Blake; and I find the following remark in a lecture recently delivered by a biologist and palæontologist (Prof. L. C. Miall, "The Life and Work of Charles Darwin," Leeds, 1883, p. 31):—"The Darwinian has to make much of the imperfections of the geological record, in order to avoid the inference that the divergence of animal forms has seldom extended to classes; seldom, indeed, to orders. I am willing to concede all that is asked on this head; but I cannot as yet find in Palæontology the proof, and, indeed, hardly the possibility, that all animal life has had a common origin."

It has been observed in all areas where the Archæan rocks are developed that no minute order of succession can be made out, but in many areas the following general succession occurs in ascending order:—

1. Highly metamorphosed, often foliated rocks.
2. Less highly metamorphosed rocks, rich in green silicates, and often foliated.
3. Unmetamorphosed lavas and ashes.

The rocks (2), according to the supposition of their volcanic origin above advocated, would, as already explained, be merely the same rocks as (1) which had not been sufficiently deeply buried to become so highly altered, and it is noticeable in connexion with this that they are usually less penetrated by granites.

The rocks (3) would be formed, as described, after the removal of much of (2) and some of (1) by denudation, and we may therefore expect to find them resting sometimes on (2) and sometimes on (1) and presenting discordance of dip with these.

Lastly, the various doubtful unconformities which have been recorded in the Archæan rocks may be in many cases due to denudation of the volcanoes during periods of comparative volcanic quiescence, and the accumulation of agglomeratic fragments perhaps rounded by pluvial action upon the eroded surfaces of the older pyroclastic rocks.

This view of the origin of the Archæan rocks is of course only to be confirmed or otherwise by rigid microscopic examination of the rocks themselves, but I have thought that it would be useful to draw up these notes in order to show how many actual difficulties do occur, which there is often a tendency to overlook.

REVIEWS.

I.—DR. BARROIS' GEOLOGY OF THE OLDER ROCKS OF THE ASTURIAS AND GALICIA.

(SECOND NOTICE.)

THE Lithology of this fine work has evidently received most careful attention on the part of the author, and hence we find that this portion of the subject has the post of honour assigned to it, whilst the book itself is dedicated to the well-known petrographers, Messrs. Fouqué and Michel-Lévy, in acknowledgment of the assistance obtained from the College of France in this department. Dr. Barrois chiefly concerns himself with the lithology of the palæozoic schists and quartzites, and with that of the massive crystalline rocks; but in the stratigraphical portion of the work the description of the "*terrain primitif*" (Archæan) is so essentially based on its mineral composition and rock structure, that this also falls within the lithological section, although relegated to an entirely different chapter (pp. 387–406).

We have then to consider three divisions of the subject, and it may