AN OUTLINE OF THE GEOLOGICAL HISTORY OF THE EDEN VALLEY
OR EDENSIDE.

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Compiled from various published sources of information, and communicated
to the Association by permission of the Director-General of the Geo-
logical Survey.

(*Read July 5th, 1889.*)

The geology of the parts of the "Eden Valley"* to be visited during the Long Excursion of 1889 is so varied, and, in many of its details, so complicated in structure, that the comprehension of some of even the broader features will hardly be possible without some kind of conspectus of the history of the rocks as a whole. When the outlines of the history of each formation have been mastered it will be a comparatively easy task to comprehend their inter-relations in the field, and to understand the long series of changes that have ultimately led to the appearance of the several rocks at the surface in their present positions.

The distribution of the several formations is shown in a generalized way on the small geological map, Fig. 1. Their stratigraphical relations are shown to some extent by Fig. 2, which passes across the Lake District from south to north.†

The general character of the surface relief is seen by reference to the contoured map at the end. (Fig. 17).

The following table shows the general succession of the rocks in descending order, together with the positions and proportions of the principal breaks in the strata:—

Various forms of Recent and Glacial Deposits.

OLIGOCENE DYKES.

? Remains of Cretaceous Rocks off the West Cumberland Coast.

* It is better to employ the old name Edenside for this district between the Lake District and the Pennine Escarpment.

† Lent by Mr. H. B. Woodward.

FIG. 1.—Geological map of Cumberland and Westmoreland.

Unconformity. Position of Third Plain. Break of several thousand feet.

JURASSIC ROCKS.

NEW RED (4,000 feet).

- (a) Upper New Red—(1) Stanwix Marls, etc., (2) Kirklington, St. Bees', etc., Sandstones, (3) Lower Marls.
- (b) Magnesian Limestone and Plant Beds.
- (c) Penrith Sandstone and the Brockrams.

Great Unconformity. Position of Second Plain. Break of two miles or more.

CARBONIFEROUS ROCKS (7,000-12,000 feet).

- (a) (1) Coal Measures, (2) Millstone Grit.
- (b) (1) Yoredale Rocks, (2) Mountain Limestone, including the Calciferous Sandstone and the Roman Fell Beds.
- (c) Upper Old Red.

Great Unconformity. Position of the First Plain. Break of five to six miles.

? MIDDLE OLD RED.

Break of undetermined extent.

SILURIAN ROCKS (10,000 to 14,000) feet.

- A (a) Kirby Moor Flags (Ludlow). 2,000 feet.
- (b) Bannisdale Slates (Ludlow and Wenlock in part.) 5,200 feet.
- (c) Coniston Grits and Flags (Wenlock Shale). 6,200 feet.
- B (a) Pale Slates. 500 feet.
- (b) Graptolitic Mudstone, and Cautla Conglomerates. Break.

ORDOVICIAN, Lower Silurian, or Upper Cambrian. (20,000 feet).

- (a) Bala Sedimentary and Volcanic Rocks.
- (b) Borradale Series, together with the contemporaneous Milburn Rocks and the Ingleton Green Slate Series.
- (c) Skidda Slates (older part).

Various rocks of Plutonic and Metamorphic origin.

I.—OLDER PALÆOZOIC ROCKS.

Taking these rocks in chronological order we come first to the Skidda Slates. These consist of a pile, from ten to twelve thousand feet or more in thickness, of alternations of thin argillites, flags, and sandstone, with a few beds of conglomerate. The whole series is of marine origin.

The fauna, on the one hand, and the stratigraphical evidence on the other, point to these rocks as the equivalents in time of the Welsh strata from the Llandeilo rocks down to, possibly, the Lingula Flags. The fossils include many forms of graptolites of Ordovician types, together with a peculiar assemblage of trilobites, phyllopoas, brachiopods, and some mollusca proper. The rocks exhibit a very remarkable uniformity of lithological character in both their horizontal and their vertical extent.

Locally, contact-metamorphism has converted the argillaceous members of the series into andalusite-schists, while the arenaceous strata have passed into the condition of mica-schist. South of an east and west line through Cross Fell the argillaceous members of these (and of the other Siluro-Cambrians) are affected by cleavage. To the north of that line cleavage gradually becomes imperceptible.*

During the later part of the Skidda Slate period volcanic eruptions commenced along a zone ranging in a north-easterly direction through where Keswick is now. Lavas, tuffs, and coarse agglomerates, chiefly of an andesitic character at first, accumulated around the vents at a higher rate than that of the local subsidence then in progress, so that the cones, at an early period, extended well above the sea-level; therefore, in the main, these rocks are of subaërial origin. There is reason for believing that the rate of subsidence was not by any means uniform over the whole district, and that, especially in the northern part of the area, elevation and consequent denudation of the Skidda Slates went on contemporaneously with subsidence and the formation of newer rocks in the south.

The main centres of eruption are now mostly buried beneath newer rocks, but one of these old necks, much altered by proximity to another vent of Old Red age, is now represented by the gabbro, etc., of Carrock (Carrick) Fell. The coarser

* 'Geol. Mag.,' II, x, p. 399.

N.

S.

FIG. 2.—Generalized Section across the Lake District from the Solway on the North to Ingleton on the South. (Kindly lent by Mr. H. B. Woodward, F.G.S., from his 'Geology of England and Wales.')

7. New Red. 6 & 5 Carboniferous. 4. Kirkby Moor Flags, Bannisdale Slates, Conistone Grits and Flags, Pale Slates, and Graptolitic Mudstones. 3 & 3a. Borrowdale Series and Conistone Limestone, &c. 2. Skidda Slates. 1 & 1a. Granites.

N.W.A.

S.E.

FIG. 3.—Generalized Section across the Cheviots from N.W. to S.E. to show the relation of the Carboniferous Rocks to the Middle Old Red, and of this to the Silurian. (Kindly lent by Mr. H. B. Woodward, F.G.S., from his 'Geology of England and Wales.')

A. Silurian. B. Middle Old Red. C. Upper Old Red. D. Calcareous Sandstone (= Mountain Limestone of Westmoreland) E. Yoredale Rocks.

N.

S.

FIG. 4.—Generalized Section through Ingleboro', from North to South, to show the relation of the Carboniferous Rocks to the Siluro-Cambrian Rocks beneath. (First Plain.) (Kindly lent by Mr. H. B. Woodward, F.G.S., from his 'Geology of England and Wales.')

6. New Red. 5. Coal Measures. 4. Millstone Grit. 3. Yoredale Rocks. 2. Mountain Limestone. 1b. Bala Rocks.

1. Ingleton Green Slate Series.

accumulations of agglomerate, some including ejected blocks many tons in weight, mark approximately the sites of other vents.

Away from the line mentioned as occupied by the cones the material tends to become finer, and, as might be expected, locally gives place to sedimentary deposits. Some of the contemporaneous waste of the rising area of Skidda Slate, mingled, more or less, with re-sorted volcanic material, may now be represented (as I have before pointed out *) by the Ingleton Green Slates, which the Association visited during the Long Excursion of 1882.

To the east of the line of vents—or, in other words, along the seaward margin of the old volcanic area—a different type of rocks was laid down at this period. Their relation to those of the typical area may be best understood by reference to the annexed diagram :—

Fig. 5.—Diagram showing the submarine equivalents of the Borradale Volcanic Rocks :—

The evidence shows that for a long period very little of the material ejected from the old volcanoes extended far to the east. Deposition of sediment, such as forms the ordinary Skidda State, seems to have gone on through thousands of feet without perceptible intermixture of erupted material. After a time, however, when the cones had attained to large dimensions, a more violent outbreak than usual shot forth the fragments of lava, etc., with sufficient force to reach the sea-bottom miles to the east of the vents. Thus beds of submarine tuff were formed.

* 'Proc. Geol. Assoc.' Vol. ix, p. 478. See also the Section through Ingleboro, Fig. 4.

Then, as the paroxysms abated, ordinary sedimentation was again resumed, and beds of Skidda Slate were again deposited. But with further growth of the old volcanoes parasitic cones grew upon their flanks, and the eruptions were thus extended over an increasingly larger area, and a larger proportion of submarine tuffs came to be laid down. The alternations of Skidda Slate and submarine tuffs thus deposited on the eastern flanks of the principal area of eruption I have often referred to as the *Milburn Rocks*, from the village where this type is best exhibited.

By the time the Bala Period had set in the growth of the parasitic cones had extended the subaërial volcanic rocks over an immensely large area, and we accordingly find fossiliferous sedimentary rocks containing Bala types of fossils, interstratified with tuffs and lavas.

The later eruptions seem to have been chiefly rhyolitic in character, though eruptive rocks of an intermediate, or even of a sub-basic type are also represented; but, on the whole, the more ancient volcanic material is of a less acid composition than the newer, instead of the reverse, as is commonly the case.

The foregoing observations will serve to make it clear why the principal volcanic rocks to be examined during the present Excursion belong to the later part of the Borradale Period. While the lower beds of volcanic material were being piled up in the central area there was nothing but ordinary sediment being laid down in the submarine area to the east. It was only when about half the entire thickness had been accumulated in the Lake District that occasional showers of tuff fell as far out to sea as where, say, Milburn now is; and it was not until the old volcanoes had nearly attained their maximum development, which was in the later part of the Bala Period, that the easterly extension of the parasitic cones to this area transported materials in quantity sufficient to preclude the formation of ordinary marine sediment.

As mentioned above, Bala stages of evolution had set in long before the close of the volcanic episode; and the characteristic life-forms of that period flourished in abundance on the old sea-bottom in the intervals between the more violent paroxysms. Even when the nature of the eruptions was such as to drive the animals away for a time, their modified descendants and their

relations returned again and flourished as their ancestors had done before. Some of the beds of limestone formed at this period consist almost entirely of the unworn remains of encrinites, trilobites, brachiopods, and mollusks.

But there were areas around the principal cones that were not submerged until after the last eruptions had ceased. So the Coniston Limestone, as will be seen by a reference to the Geol. Survey maps, 98 N.E. and N.W., was almost the only bed of sedimentary origin that extended across this particular area. The Association will have a good opportunity of comparing with this thin stratum the fine development of Bala Rocks accumulated on the seaward flanks of the old volcanoes. On the S.W. face of Roman Fell these are seen to be many hundreds of feet in thickness, as they are in Craven.

With the Coniston Limestone and its chronological equivalents terminates the last record of Ordovician events in Cumberland and Westmoreland. Continuous subsidence had been going on to a depth of twenty thousand feet or more; and it seems that the time had arrived when movements in the opposite direction began to prevail. Many geologists maintain on good grounds that here, as in Wales and in Craven, the close of the Ordovician period was marked by the advent of considerable disturbance, upheaval, and denudation of the older strata. Whether the rocks of Cumberland and Westmoreland remained unaffected is a point much disputed; but those who have gone over the Craven area with Professor Hughes's memoir* in hand cannot well have much doubt about the magnitude of the disturbances and denudation that ensued there at the time now referred to. At all events, and whatever happened, we find ourselves at this point face to face with one of the most difficult, and therefore one of the most interesting, problems the student of Palæozoic geology has to deal with. The facts are of this kind:—Two kinds of fossiliferous rocks have been herein mentioned so far. The older is the Skidda Slate, which contains a well-marked graptolite fauna, about which there is not much room for dispute; and the newer (locally separated from the older by many thousands of feet of strata) is the Bala series. Graptolites have not hitherto been found in this—presumably because graptolites required pecu-

* 'Geol. Mag.,' Vol. iv, p. 346.

liar life-conditions which did not happen to obtain in this region during the Bala period. Now the next bed above the Bala beds in Cumberland and Westmoreland is simply crowded with graptolites, and with forms too, be it noted, that palæontologists were wont, not so long since, to refer unhesitatingly to Llandeilo horizons. In other words, a "Llandeilo" graptolite fauna was found in a stratum distinctly overlying another stratum about whose Bala age there could be no doubt.

But the anomaly does not end there. The Graptolitic Mudstone—the bed referred to—is locally unconformable to the beds below, in some cases to a considerable extent. More than that, it clearly and unmistakeably graduates upward into the Silurian Series, of which there can be no doubt that it forms, with its conglomerate, the natural base. The rock itself will be seen during the present Excursion. It consists of dark brown, or sooty mudstones, with somewhat the texture of indurated Fuller's earth; and, as I have mentioned above, is crowded with graptolites. For further details regarding these, and the rock generally, reference should be made to Messrs. Marr and Nicholson's paper in the 'Quarterly Journal of the Geological Society,' November, 1888, p. 654, *et seq.* The Graptolitic Mudstones are not many feet in thickness, and near their top they begin to graduate, by interlamination, into a mass of peculiar pale grey-green, felsitic-looking "mudstones," the so-called Pale Slates. These (except in their darker bands) are unfossiliferous. Near their top the Pale Slates, in their turn, graduate upwards by interlamination into the finely striped dark blue argillites known as the Coniston Flags. Of these we shall see only the base. Above them, in uninterrupted succession, were deposited, over an extensive area, the Coniston Grits, the Bannisdale Slates, and the Kirkby Moor Flags, whose aggregate thickness, from the base of the Graptolitic Mudstone to the highest bed seen, amounts to above twelve thousand feet.

These higher beds are full of interest; but it is only with their base that the Association is at present concerned. The basal Graptolitic Mudstone, as I have said, contains a graptolite fauna that retains much of the peculiar facies of those of Ordovician times. The Mudstones graduate upward insensibly, through the Pale Slates, into the Coniston Flags; while they are

separated from the Ordovician beds below by an unconformity more or less marked. Now the Coniston Flags, as the Association will have an opportunity of seeing, also yield graptolites. In this case, however, these organisms are as clearly Silurian in facies as those occurring in their natural base are Ordovician. What has happened? Clearly we have here a case (not by any means an isolated one) where the breaks in the succession of life do not coincide with the breaks in the succession of the strata. If we listen to our palæontologists we must classify the Graptolitic Mudstones with the Ordovicians; while, if we are guided by the physical evidence alone, then the Graptolitic Mudstones with their Ordovician fauna must go in the same group with the beds above and be classed as Silurian. It will never do to close our eyes to these facts, especially as they do not by any means stand alone. Probably no explanation that may be given will ever prove satisfactory to both geologists and palæontologists alike. One such theory—based upon the assumption that the graptolites of the later fauna were the modified descendants of those living in early Ordovician times; and, further, that graptolites in general, like ammonites in later times, could exist only under conditions that were exceptional—may be given here. When the Ordovician volcanoes broke out graptolites could not of course live in their immediate neighbourhood; but they certainly did not all migrate to a great distance, for *Didymograptus murchisoni*, and others also, may be found quite commonly in the bands of Skidda Slate alternating with the tuffs of the Milburn Rocks. Doubtless an enormous interval of time is represented by the vast thickness (12,000 feet) of the Borradaile series. To that we have to add the time required for the formation of the Bala rocks; and again, there is the great interval represented by the gap between the close of the Ordovician and the commencement of the Silurian period. During this time (which may have far exceeded the whole time represented by the British Secondary rocks) the graptolites, generation after generation, migrated from area to area, gradually evolving new forms and eliminating older ones as time went on. In course of time one of the great terrestrial undulations travelling in this direction propagated a downward movement of the earth's crust as far as this. As the depression advanced hither the

migration of the graptolites proceeded *pari passu* with it; and eventually the belated survivors of the Ordovician Rhabdophora reached the spot, whence, millions of years before, their ancestors had been driven by adverse circumstances. For a time they held their own and did well; but the subsidence that ushered in the Graptolitic Mudstones was only the commencement of a great movement that carried the sea-bottom here down to unusually great depths. Deep oceanic conditions prevailed, and the old colony of graptolites either migrated still further, or else it became completely extirpated here. The Pale Slates, if I read their history aright, represent a deposit of oceanic ooze, which must have required many millions of years for its accumulation—long enough to admit of the evolution and the subsequent extinction of two or three successive faunas. After a time the ocean-bed gently rose, thalassic (*i.e.*, infra-littoral) conditions took the place of oceanic, films of impalpable mud, derived from the land, again began to be laid down, and the formation of the Coniston Flags commenced. With the advent of the new conditions graptolites again occupied this station; but this time they migrated from a different zoological province, and, as a consequence, they were different in character from their predecessors on the same spot, and represented a much later stage of evolution than did those that preceded them.

The question is one worthy of the most careful consideration, not only in connection with the rocks under notice, but also in the case of the Middle Old Red in relation to the Upper Old Red and the Carboniferous rocks; or, again, in connection with the Carboniferous fauna in relation to that of the Magnesian Limestone. In all of these the older faunas have survived through the long interval of time represented by important unconformities; and the older forms of life have given place to the newer within the limits of a conformable series of rocks. In other words, in these cases, the stratigraphical and the palæontological breaks do not coincide.

II.—POST SILURIAN CHANGES.

After the Silurian ocean-bed had subsided through a depth of twelve thousand feet or more we lose sight of the history of the Lake District for a long time. All we can say is that the rocks,

some time afterwards, were subjected to faulting, disturbance, and denudation enormous in extent. Subsequently they underwent that curious, and, even yet, imperfectly-understood process that resulted in the development of cleavage. The cleavage is not due to the pressure that produced the contortions of the rocks; nor is it due to pressure alone, as we have so often been told is the case. Here, at all events, cleavage is not in any way connected with the flexures of the rocks; but is of later date — Post-Silurian, but Pre-Carboniferous.

III.—MIDDLE OLD RED.

After the Siluro-Cambrian rocks of Cumberland and Westmoreland had been consolidated, disturbed, denuded and cleaved, it is more than likely that they were for a time buried up beneath a considerable thickness of the Middle Old Red, which was of mixed lacustrine and volcanic origin, and whose remnants are left, even yet, just beyond the limits of the district, and, possibly, also here and there under the newer deposits of Cumberland itself. The relation of the two sets of rocks to each other and to the Upper Old Red is shown in the diagrams, Figs. 3 and 6.

Probably most of the chief plutonic rocks of Cumberland and Westmoreland date from this Middle Old Red period of volcanic activity, including the granite masses, which are regarded as the deep-seated cores of the Old Red Volcanoes. Also it was at this period that the chief metamorphism of the older rocks was effected.

IV.—UPPER OLD RED.

After the close of the Middle Old Red period this area was again affected by disturbance and denudation. I believe that it was at this period that the initiation of the Pennine Fault took place. Nearly, or quite, all the previously-formed Old Red was denuded, and part of its remains, whether volcanic or detrital, was worked up anew into shingle. I have long known that the materials of the Upper Old Red in Cumberland and Westmoreland consisted largely of re-sorted conglomerates, partly derived from Scottish areas, partly from Middle Old Red porphyrites, partly (though to but a very small

FIG. 6.—First Plain.

FIG. 7.—Second Plain.

FIG. 8.—Third Plain.

FIG. 9.—Existing surface, as denuded out of the Third Plain.

extent) from local sources.* At any rate, the Upper Old Red levelled up the hollows in the old surface, and then the land again subsided and the formation of the Carboniferous rocks commenced. The relation of these rocks to those beneath, and to the surface (or First Plain) on which they lay can best be gathered from an examination of the series of diagrams, Figs. 6, 7, 8, and 9.

It should be noted here that the First Plain now referred to extends, locally, with marvellous evenness of contour, across the edges of quite five miles of strata, in this district alone. A striking illustration of the same feature is presented by Fig. 4, which is borrowed from Woodward's 'Geology of England and Wales,' and was originally drawn partly from one of Professor Hughes's sections.

The evenness of junction seen here is generally characteristic of the First Plain. This, as will be seen presently, plays an important part in the evolution of the scenic features of the district under notice. Figs. 10 and 11, lent by the Council of the Geological Society, further illustrate the same relation.

V.—CARBONIFEROUS ROCKS.

In places, there is a passage from the Upper Old Red into the Carboniferous rocks, but the advent of the Carboniferous period as a whole was marked by a considerable change of physical conditions. As the Members of the Association will have abundant opportunities of seeing for themselves, the source of the materials, and especially of the coarser materials, forming the Carboniferous rocks, was evidently different from that which supplied the materials of the older deposits beneath. At Roman Fell, for example, the lowest beds of the Carboniferous rocks are chiefly conglomerates, which consist of little else than vein-quartz, without any admixture of materials recognizable as derived from any of the known older palæozoic rocks. On the other hand, the Upper Old Red, which we shall see close by, contains very little quartz, and is full of rocks like the Cheviot Porphyrites, the Silurian rocks of the Southern Uplands of Scotland, and even gneisses and other

* See J. G. Goodchild, "Geological History of Kirkby Stephen," etc., 1884, in Braithwaite's Guide.

FIG. 10.—Diagram Section from the Howgill Fells to Roman Fell.
(‘Q. J. G. S.,’ 1874, p. 395.)

Siluro-Cambrian.

Carboniferous Limestones.

Upper Old Red.

Carboniferous Shales, &c.

Carboniferous Sandstones.

New Red.

N.W. Cross Fell.

Roman Fell.

Brough. S.E.

FIG. 11.—Diagram Section along the Cross-Fell Escarpment.

foliated metamorphic rocks, which are evidently foreign to English ground.

With the advent of the Roman Fell Conglomerates terminates the enormously long period of disturbance, vulcanicity, upheaval, and denudation that prevailed after the close of the Ludlow period. Thenceforward, for some considerable time, this area again coincided with one of steady and long-continued depression, with which sedimentation nearly or quite kept pace. Deep-water and thalassic conditions prevailed at an early period in eastern Westmoreland and the parts adjoining. An old ridge extended in a general east and west direction through West Cumberland and Cross Fell. On the north side also deeper-water conditions prevailed, but as the main source of the materials forming the Carboniferous rocks lay to the north-west, thalassic conditions seem to have prevailed, on the north of the ridge, only near where the Lake District is now. (This and many other reasons, as I have repeatedly stated, point unmistakeably to the conclusion that the present Lake District does not represent a fossil island of Carboniferous age re-exposed by denudation. On the contrary, I have long maintained that the *massif* itself dates no farther back than Miocene times. Of this more presently.) More than two thousand feet of limestone was formed, almost without any partings, in the deep-water where now is South-East Westmoreland. Not so much as a fathom of it has any claim to be regarded as a coral-reef. Corals flourished there, and in great abundance, as regards both species and individuals. But of coral-reefs there are absolutely none. The quartz-conglomerates of the Roman Fell Series are on the horizon of the lower part of this great mass. The Calcareous Sandstone of Scotland and the Border is the sedimentary representative of the whole.* After the formation of the Mountain Limestone the same conditions were continued, with some breaks, and the Yoredale Rocks were formed. The typical Yoredale Rocks are found in the parts of Yorkshire adjoining the Lake District, and, in truth, the Yoredales to be seen by the Association during the 1889 Long Excursion have an equal claim to be regarded as typical. Those of the Pendle and

* J. G. Goodchild "On some Carboniferous Conglomerates in the Basin of the Eden," 'Q. J. G. S.,' xxx, p. 394.

Clithero district are of another type entirely. The Yoredale rocks exceed two thousand feet in thickness here. Above them comes the base of the Upper Carboniferous, *i.e.*, the Millstone Grit, which in Westmoreland equals in thickness the beds next below. Then came a vast, but unknown, thickness of Coal Measures. I have shown* on a former occasion that the Coal Measures once extended continuously over the whole district. Perhaps other rocks may have occurred as well; but if it was so, they have been removed without leaving any trace behind.

VI.—POST CARBONIFEROUS ROCKS.

Continuous deposition, it seems, cannot go on for an indefinite length of time. Sooner or later the downward phase of the undulation is at its lowest point, and a movement begins in the opposite direction. Perhaps it would be more correct to say that each terrestrial undulation is steadily, if slowly, travelling onward in a certain direction, and that an upward movement affects, in time, any given spot, as a necessary consequence of the downward movement that preceded it. Irregularities of upheaval and subsidence, more or less disturbance of the strata, with outbursts of volcanic action, mark so many of these changes that the coincidence must be more than merely accidental. At any rate, it was long after the close of the Carboniferous period before any newer strata now in existence in the district under notice came to be laid down. The rocks had evidently been much disturbed, there had been very irregular upheaval, the beds had been again disrupted along the ancient lines of weakness presented by the Pennine Fault, and a prodigious amount of denudation had taken place, before the New Red had begun to be deposited. Judging by the facts I should say that the denuded ends of the Palæozoic rocks over a large area had been weathered into a "base level of denudation," to use Mr. Geikie's phrase. (See Fig. 7.) It was not as even, perhaps, as the First Plain, but all the rocks here were weathered down to one pretty uniform level. A good illustration of this Second Plain is given in Horizontal Section 105 of the 'Geol. Survey.'† There is no evidence what-

* 'Trans. Cumberland and Westmoreland Association,' No. 7, p. 163.

† Mr. H. B. Woodward ('Geol. Eng. and Wales,' second edition, p. 232) refers to the evenness of this surface at the base of the Neozoic rocks. The same fact has been repeatedly noticed elsewhere by others.

ever that any single feature now existing had then come into being. Not the Lake District, and certainly not the Pennine Escarpment. These had undergone disturbance, but they were not left as ridges or as islands.

VII.—NEW RED.

An irregular upheaval followed the period of denudation referred to, or it may have been in part contemporaneous with it, as Mr. Geikie has shown was the case with the Old Red of Scotland. In this instance, as in the case of the Old Red, volcanic action seems to have been concerned in bringing about some of the peculiarities that characterized the period. Inequality of upheaval appears to have converted several large hydrographical basins into great inland lakes, into which the drainage of the areas adjoining, together with the waste of the surface around, gradually accumulated and formed the local base of the Neozoic Rocks. The prevailing directions of false-bedding in the earlier formed of these New Red sediments show unmistakeably that the rivers flowed from the east westward. (These rivers, it must be remembered, were not, in any way soever, connected with any features at present existing. It cannot be too often repeated that not a single feature of any kind now existing had come into being at this time.) There was much floating ice adrift in the old lakes on the break-up of the winter. The finer sediments dating from this period contain, in many places, large boulders, which have evidently fallen through the water of the old lake in such a manner as would have happened if melting cakes of shore-ice, charged with stones and mud, had floated out into deeper water, and dropped their burdens as they were released by the melting of the ice in the spring. Some of the beds of breccia ("Brockram"), near Appleby, must have originated in this way, though the phenomena are even better exhibited in the neighbourhood of Kirkby Stephen. Naturally, such deposits are not continuous over any large area, and we need, therefore, feel no surprise that the Brockrams seen at Appleby and in Helton Beck pass horizontally into the undivided mass of the Penrith Sandstone, as they trend in the direction of that town.* The deepest part of the old lake

* "Penrith Sandstone," *Trans. Cumb. and West. Assoc.*, ix, p. 31; first published in the '*Carlisle Patriot*,' 1881.

under notice seems to have been nearly along a line passing through Appleby and Helton. Here a mass of sandstones and breccias accumulated to a thickness of considerably over a thousand feet. Further west the thickness of the Penrith Sandstone diminishes, until it is reduced, locally, to nothing, in the northern parts of Cumberland. Curious and interesting chemical changes seem to have been in progress during the deposition of the Penrith Sandstone. The waters of the old inland lake appear to have been charged with various salts from an early period—perhaps because nearly the whole of the inland drainage was dissipated by evaporation. Sulphate of lime, carbonate of magnesia, chloride of sodium, etc., existed in unusually high proportions, and the nature of the sediments deposited was much affected in consequence. In the case of the Penrith Sandstone, for example, we have an enormous mass of quartzose sandstone without hardly a trace of mica anywhere in it—a feature almost unique of its kind. The mica and some of the other silicates appear to have undergone decomposition as fast as they were swept into the lake; and subsequently much of the silica thus liberated was re-deposited on the grains of quartz. By this means the quartz-granules grew up into very perfect doubly-terminated hexagonal pyramids of quartz, whose perfect faces, existing in millions in every cubic foot of some parts of the stone, impart the characteristic sparkling effect so well seen in the Penrith Sandstone.

Then, again, the presence of carbonate of magnesia reacted upon the fragments of limestone and converted them, as the Association will see, into more or less pure dolomite.

Some of the limestone fragments, again, have been largely replaced by hæmatite; and we shall see fragments in the Brockrams near Appleby, that were simply of ordinary carbonate of lime when first dropped into the lake, but now consist, through molecular replacement, of nearly pure hæmatite, just as if they were of hæmatite of older date than the New Red, instead of newer.

The sulphate of lime produced some effects whose importance is even yet not fully realized. It has long been a puzzle how it is that Red Rocks of all ages contain so few plant-remains, or none at all. We can understand why animal-remains are so few; because no animals could well thrive in a strong mixture

of various salts; but in the case of the plants the cause of their absence is not at first so clear. It has occurred to me lately* that the real explanation is that all the vegetable organisms swept into the lake were rapidly decomposed by the excess of sulphate of lime present in the water. This view tallies well with the facts, because, in the Helton section we shall see one zone, marking a period of minimum salinity, where the sandstones are of the ordinary kind, and where the plant-remains are to be found even yet in tolerable abundance. These are the celebrated Helton Plant-Beds, one of the principal objects to be inspected during the Long Excursion of 1889. These beds have yielded to the researches of Prof. Harkness and others a fairly large assemblage of plants, of Neozoic affinities, although they are older than the Magnesian Limestones, as we shall see.

The period of minimum salinity that favoured the preservation of the plant-remains at Helton seems gradually to have again returned to former conditions. Precipitations of dolomite, in cakes all more or less lenticular and discontinuous, ensued, and the Magnesian Limestone was formed. In Helton Beck

FIG. 12. —Section along Helton Beck between Great Ormside and Roman Fell, showing the succession of the New Red Rocks.

Lent by the Council of the Geological Society.

Length 5 miles. (Harkness, 'Q. J. G. S.,' 1862, p. 207.)

11. Upper sandstones (700 feet).	4. Penrith Sandstones and breccias (1200 feet).
10. Red Shales (100 feet).	
9. Magnesian Limestone (7 feet).	
8. Dark-coloured sandstone (6 ft.).	} Fossiliferous series.
7. Grey shale (3 feet).	
6. Thin-bedded red sandstone (50 ft.).	
5. Plant-beds (20 feet).	
	2. & 3. Old Red conglomerate and Carboniferous rocks.
	1. Older Palæozoic rocks.

* See 'Geol. Mag.,' July, 1889, p. 314.

this is represented by several thin bands more or less arenaceous and impure in character; but in the Bela section, only a few miles to the east, this bed is not less than thirty feet in thickness. Assuming that we are dealing with a wedge of this rock, with its base to the east, the observed rate of thickening would, if prolonged at a uniform rate, far exceed any thickness recorded in Durham, at the distance of that city from Helton. So there is no reason why the Magnesian Limestone should not have been continuous from the one place to the other; continuous, that is, as far as could be expected of such a chemical precipitate. (Fig. 12).

Before passing to the higher beds, it is important to observe that animal life in the Lower New Red, which is locally represented in such profusion elsewhere, is here entirely absent. There is not so much as a single shell, or a bone, to be found anywhere in these beds. The Penrith Sandstone (=Rothe liegende) does, it is true, yield traces of life. But these vestiges are confined to fossil impressions of the footmarks of the strange, uncouth, animals that wandered on the shores, or waded in the shallows, of the old lakes. Mr. G. Varty Smith's researches* have brought to light many different forms of these animals. They seem to have been, in form, something like *Iguanodons*, as they threw the main weight of their bodies upon their larger hind limbs and their tail, and only used their fore-limbs in much the same manner as a kangaroo does. The Jardine Collection of these footprints, from Dumfries, now in the Edinburgh Museum of Science and Art, shows an extraordinary variety of these ichnites, which would seem to entitle the Lower New Red to the designation of the Age of Reptiles almost as much as the Jurassic rocks. Whether these animals belonged to the *Sauropsida* or to the *Ichthyopsida* the evidence at present existing will not enable us to judge.

After the deposition of the Magnesian Limestone occurred a somewhat abrupt change of conditions, and again a high degree of salinity. It was then that the Lower Gypseous Marls (the base of the Bunter as many think) were formed. These marls graduate upwards into the St. Bees' Sandstone, which will be examined in several localities under the President's guidance. At Helton Beck these yield desiccation-marks, ichnites similar

* 'Q. J. G. S.,' xl, 479.

to those in the Penrith Sandstone, casts of bay-salt, rain-spots, and other evidence of shallow-water conditions. These sandstones accumulated to a thickness of quite two thousand feet. In many parts they are much mottled, poikilitic, bigarré, or Bunter; and they locally become more or less pebbly.

What happened after the deposition of the St. Bees' Sandstone is a question much in dispute. Mr. Holmes has much to say upon that head. (*Vide supra*, p. 246.)

At any rate, whatever beds were deposited next above have been denuded from the greater part of the district specially under notice. I have no doubt, in my own mind, that all the rocks up to the Lias, and even all the Jurassic rocks, once overspread the whole district, and were continuous with those of other parts of the kingdom. The Pennine Fault and the disturbances that accompanied that disruption, have facilitated the removal of those rocks over certain areas, while they have, on the other hand, helped to preserve them elsewhere.

VIII.—POST JURASSIC EVENTS.

From Lower Jurassic times onward we lose sight of the history of Edenside until Miocene (or Oligocene) times. Then, as we know, great disturbances affected these parts, and the Armathwaite (Cleveland) Dyke was intruded. But although direct evidence is wanting, many considerations have led me to believe (and to state in print again and again) that after Jurassic times this area, and much around it, underwent extensive denudation, which resulted in the formation of what I term the Third Plain (See Fig. 8). Then the land subsided and the Cretaceous rocks were spread out far and wide over what are now hill and valley. In those times, as the diagrams will show, none of the features now existing had been developed. I believe that nearly all our mountain plateaux belong to this Third or Subcretaceous Plain, and many other broad surface features also.

IX.—FIRST APPEARANCE OF THE MOUNTAINS.

Then, long subsequently, and possibly in Middle Eocene times, the whole area underwent its last and most important upheaval. The land then assumed for the first time the character of a permanent terrestrial surface, and the courses of the rivers of the district were also, for the first time, marked out. A reference to Fig. 9 will serve to make this clearer. It will be seen by this that

the rivers did not flow then quite as they flow now. The main water-shed of northern England lay then, not where it is now, but above the lowlands of Edenside. The inosculating valleys, and many other anomalies in the courses of the rivers, are quite inexplicable on any other theory than that all the principal rivers of northern England took their rise somewhere above where Appleby is now. This subject is discussed in some detail in my paper on the River Eden, published in 1880, and now reprinted in No. xiv of the 'Trans. Cumberland and Westmoreland Association.' Another aspect of the same question is discussed in my 'Physical History of Greystoke Park and the River Petteril,' in No. xiii of the same journal.

Out of the three plains so often alluded to—after they had been more or less folded, tilted, faulted, and eventually re-exposed by denudation—subaërial forces, acting through an immense period of time, have shaped all the features of first magnitude: the great plateaux, the larger lowland plain, and the escarpment. The features of secondary magnitude, as one may term them, are mainly due to variations in the ratio of horizontal to vertical waste presented by their respective rock-masses. These features, however, have been more or less modified by glacial action, which I shall now proceed briefly to describe.

X.—THE GLACIAL PERIOD.

Long after all the valleys had been shaped out, and the orography of Edenside had assumed nearly its present form, decreased summer temperature gave rise to local glaciers. For a very long period these seem to have gone on increasing in proportions; but, at the same time, they appear in every case to have flowed in the same direction as the existing drainage. The principal result appears to have been the removal of nearly the whole of the rock that had been loosened by pre-glacial weathering and its transference to a lower level. This was chiefly effected along the bottoms and the sides of the valleys, which thereby were gradually both deepened and widened. Later on, still colder conditions supervened; the local glaciers became confluent; their upper surface rose to higher levels; and they advanced farther and farther across the area lying outside the mountains. There is reason to believe that this state of things continued for a long time; and that, for a

FIG. 13.

Laminated Clays and Loams more or less affected by thrust planes due to the movements of the melting ice above it. Length about 12 inches. Cutting in the Midland Railway, near Langanby.

FIG. 14.

Section across the Midland Railway near Langanby, showing alternations of Till (r.), Sand and Gravel (s. g.), and Laminated Clays (c.) overlying New Red Marl (in the right hand corner).

FIG. 15.

Disturbed Laminated Clays, probably originally deposited in nearly horizontal sheets, and afterwards deranged by lateral movements resulting from the down-settling of the melting ice-sheet above. Length of section, 9 inches. Midland Railway Cutting near Langanby.

period of great length, the whole of Edenside was occupied by one vast glacier, which, for the greater part of the time, flowed chiefly in the same directions as the drainage does at present. There seems reason to believe also that enormous accumulations of moranic material gathered in this way on the lowlands around Carlisle and in the Solway. It was here, I believe, that the chief accumulations of Shap Granite, and of the many other upland rocks that went with it in the drift, were first deposited, and it was during this period that the wonderful scoring, grooving, and glacial erosion generally, that characterizes Edenside, were accomplished. All the old lakes of Edenside—Appleby Mere, Langanby Mere, the great lake at Threlkeld, as well as the lakes now existing as such, were eroded chiefly at this period.*

By-and-bye, as the summer temperature continued to fall, and less and less of the winter's snow melted, the whole of the sea to the north-west of the British Isles became completely filled with ice. Under these conditions the northern glaciers were no longer able to flow seawards. The sea-ice pressed back the outer ends of the glaciers from the land, the ice-rivers were dammed at their mouths, and the only course open to the icy flood lay to the south. So there was set up a southward flow of the higher parts of the ice, south-easterly on the southern coast of Scotland, and south-westerly along the eastern shores of England. There was no longer an outlet for the Edenside ice by way of the Solway, for the icy flood advancing from Gallo-way stopped all egress in that direction. So, after a time, the ice around Carlisle began to flow in the lines of least resistance open to it. One of these lay eastward over the Bewcastle Fells, and thence down the valley of the Tyne to the east coast. The other direction of least resistance lay up the Eden Valley itself. So we find the glacial tide turned inland along these two directions at the time referred to. Vast quantities of *débris* were swept along in the ice in directions diametrically opposite to what they had taken at an earlier stage. Eventually the icy flood, closely pressed in many directions by local currents, flowed past Appleby, over the east of Roman Fell, and thence over the uplands of Stainmoor out to the Plain of York, where it

* See the lines showing the 400 feet and the 500 feet contours on the map, Fig. 16; and see also "Trans. Cumb. and West. Assoc.," xiii, p. 105.

was joined by the current that had travelled round by the Tyne Valley and the eastern parts of Durham.*

FIG. 16.

Diagram to illustrate the transportation of boulders in directions contrary to the flow of the sole of the Ice-Sheet. Ice carrying boulders down hill and outwards from the centres of dispersal in a direction from A to B, is met at B by ice-currents setting in contrary direction (in most force at higher levels). At B the opposing forces are balanced, and the direction of least resistance is then mainly upward. Arrived at higher levels, the local current becomes more and more affected by the influence of the currents setting inland, and the ice then moves with its freight of mixed local and extraneous detritus in the direction of C, D. On the melting of the ice, the sediment dispersed throughout it, is deposited on the rock surface below; the boulders, both of local and extraneous origin, between D and Z, for example, being deposited at Z. [It should be observed that in hardly any case did the direction of movement of the outflowing current lie diametrically opposite to that of the current opposing it. The curve of transportation was probably hardly ever entirely in the same plane.]

It was at this same period that the North Sea was blocked by ice, and the mouths of our south-country rivers were dammed. The brick-earths of the Thames-Valley system are simply the flood-deposits contemporaneous with the glacial phenomena of Stainmoor.†

The icy flood left its impress upon the surface in a variety of forms. I am still of opinion that the great caldron-shaped "coums" or cirques of Edenside and around were formed by the ice at this period. Interrupted ice-groovings on a large scale, a hundred feet in depth, and as many fathoms in width,

* Reference should be made to the glacial phenomena registered on the small map appended to this paper. See also "Ice Work in Edenside" ('Trans. Cumberland and Westmoreland Association,' No. xi, p. 111, *et seq.*).
 † Q. J. G. S., xxxi, and 'Geol. Mag.,' 1875, p. 360.

† "Notes on some Superficial Deposits of North Kent," 'Proc. Geol. Assoc.,' ix, p. 151.

traverse Edenside from end to end. Big troughs were scooped out along the hill-sides; ice-smoothed surfaces are nearly everywhere of common occurrence. Some of these will be seen: others are shown upon the map, Fig. 17.

It is a remarkable fact that, immediately after the climax of the Glacial period, a somewhat abrupt amelioration of the climate ensued. Certain it is that after the ice had moved inland and uphill, as I have described, it did not gradually break up into small glaciers and pass in reverse order through the series of changes whereby it attained its maximum. On the contrary, it seems to have quietly melted away on the spot without perceptible movement of any kind.

The stony and earthy matter transported in, on, and under the ice gave rise, as the ice melted, to those varied forms of glacial sediment that we call till, glacial sand and gravel, eskers, etc. (See Figs. 13, 14, 15, and 16).

Some time after the ice had left its stony and muddy sediment behind, a second and much less severe period of cold set in; and small local glaciers occupied a few of our mountain valleys. These minor glaciers, however, accomplished little else than the transfer of some of the older Glacial Drift to lower positions outside. Some of these later moraines will be seen by the Association at Cosca, near Dufton, and elsewhere.

Since the Glacial period subaërial denudation has accomplished results so trifling, in Edenside, at all events, that one may hesitate to believe that the close of that period can be distant from our own time more than a few thousand years at the very most.

APPENDIX.

For a list of works relating to the Geology of Cumberland and Westmoreland reference should be made to Mr. Whitaker's Bibliography, published in the 'Trans. Cumberland and Westmoreland Association,' No. vii, p. 13.

Since that list was printed, several publications of more or less importance have appeared. Among these may be mentioned the following:—A second edition of the Geol. Survey 'Memoir on the Geology of the Country around Kendal, Sedbergh, and Seba,' which has been edited, and, in part, re-written, by A. Strahan,

M.A., F.G.S. Messrs. Aveline and Hughes' account of the Silurian rocks of the Lake District, in the 'Memoir,' should certainly be read by those intending to take part in the Excursion. For a concise account of the Ordovician rocks as a whole, read Mr. Ward's "Physical History of the Lake District," 'Geol. Mag.' Dec. ii, Vol. vi, No. 2, p. 49, and No. 3, p. 110. A valuable summary of the facts has already appeared in Mr. Hudleston's "Geology of the Neighbourhood of Keswick," 'Proc. Geol. Assoc.' vii, p. 213. Woodward's 'Geology of England and Wales,' 2nd ed. (1887), should also be consulted, as it contains full details of all the geological features of importance. An outline of the geological history of Westmoreland (by J. G. G.) is given in Braithwaite's "Guide to Kirkby Stephen and Appleby," Kirkby Stephen, 1884. The article—"Westmoreland," 'Encyclop. Brit.' new ed. Vol. xxiv (by J. G. G.), contains an account of the chief features of geological interest in the county. Mr. Teall's papers in the 'Quart. Journ. Geol. Soc.' should be read, especially the one in the 'Quart. Journ. Geol. Soc.' for May, 1884, dealing with the Armathwaite Dyke. Lastly, Messrs. Marr and Nicholson's valuable paper on the "Stockdale Series," 'Quart. Journ. Geol. Soc.,' No. 176, Nov., 1888, p. 654, deals with one of the most interesting features in the geology of the north-west of England, the history and the palæontology of the Graptolitic Mudstones.

Mr. Holmes's papers on the neighbourhood of Carlisle will be, of course, in the hands of all the members of the party. The list includes, amongst others, "The Permian, Triassic, and Liassic Rocks of the Carlisle Basin," 'Quart. Journ. Geol. Soc.,' Vol. xxxvii, p. 286; "Notes on the Geology of Cumberland North of the Lake District," 'Proc. Geol. Assoc.,' Vol. vii, p. 404; "Raised Beach between Whitehaven and Bowness," 'Trans. Cumb. and West. Assoc.,' No. ii, p. 68; "Submerged Forest off Cardurnock, on the Solway;" and "The Destruction of Skinburness by the Sea about the year 1305," *ibid.*, No. vi, p. 121; "Physical Geography of North-West Cumberland," *ibid.*, No. vi, p. 167;* "On the Distinctive Colours of the Carboniferous and Permian or Triassic (Poikilitic) Rocks of North Cumberland," *ibid.*, No. vii, p. 79; "Water Supply in the Carlisle Basin," *ibid.*, No. viii, p. 17; "Coal Measures below the New Red Sandstone," *ibid.*, No. viii, p. 208; "Discovery of Mammalian Remains at Silloth," *ibid.*, No. viii, p. 209; "*Bos primigenius* and the Chillingham Wild Cattle,"

ibid., No. viii, p. 211 ; " Note on Shawk Beck," *ibid.*, No. viii, p. 211 ; " Note on the best Locality for Coal beneath the Permian Rocks of North-West Cumberland," *ibid.*, No. ix, p. 169 ; " The Carlisle Water Supply," *ibid.*, No. ix, p. 213 ; " Section North of Silloth," *ibid.*, No. ix, p. 213 ; " Silloth New Dock," *ibid.*, No. ix, p. 214 ; " Changes of Channel in the Solway," *ibid.*, No. ix, p. 215 ; " Ancient Lake Dwellings in Galloway," *ibid.*, No. ix, p. 215 ; " The Probable Existence of Lake Dwellings in Cumberland," *ibid.*, No. ix, p. 217 ; " Notes on the Purple-Grey Carboniferous Rocks and the Whitehaven Sandstone," *ibid.*, No. xi, p. 146.

References to some of the papers by Mr. Goodchild are given under their respective subjects as footnotes to the paper on the " Geological History of Edenside."

J. G. G.

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* The 'Trans. Cumb. and West. Assoc.' can be obtained of the Messrs. Coward, 75, Scotch Street, Carlisle.