from sufficient to establish this hypothesis, but as it has been clearly shown that there is no relation between hours and frequency which holds good for all times and places, it is in this direction that investigation must now be turned before we can finally say that the attraction of the sun and moon has or has not an effect on the occurrence of earthquakes. If it be found that there is no diurnal periodicity corresponding to the tidal forces produced by them, it may safely be said that any periodicity of longer period, which may appear to correspond with the movements of these or any other heavenly bodies, cannot be due to their attraction; and, unless we assume a hyperphysical or astrological influence of the sun and planets, we must finally conclude that earthquakes are as purely terrestrial in their cause as in their effect.

NOTICES OF MEMOIRS.

I.—British Association for the Advancement of Science. Glasgow, September 12th, 1901.

Address to the Geological Section, by John Horne, F.R.S. L. & E., F.G.S., President of the Section.

Recent Advances in Scottish Geology.

THE return of the British Association after the lapse of a quarter of a century to the second city of the empire, which since 1876 has undergone remarkable development, due in no small measure to the mineral wealth of the surrounding district, suggests the question, Has Scottish geology made important advances during this interval of time? Have we now more definite knowledge of the geological systems represented in Scotland, of their structural relations, of the principles of mountain-building, of the zonal distribution of organic remains, of the volcanic, plutonic, and metamorphic rocks so largely developed within its borders? It is true that many problems still await solution, but anyone acquainted with the history of geological research must answer these questions without hesitation in the affirmative. In the three great divisions of geological investigation — in stratigraphical geology, in palæontology, in petrology—the progress has indeed been remarkable.

. . . .

The belt of Archæan gneisses and schists, which may be said to form the foundation-stones of Scotland, have been mapped in great detail by the Geological Survey since 1883 along the western part of the mainland in the counties of Sutherland and Ross. In that region they occupy a well-defined position, being demonstrably older than the great sedimentary formation of Torridon Sandstone and overlying Cambrian strata. The mapping of this belt by the Survey staff and the detailed study of the rocks both in the field and with the microscope by Mr. Teall have revealed the complexity of the structural relations of these crystalline masses, and have likewise thrown considerable light on their history. These researches indicate that, in the North-West Highlands, the Lewisian (Archæan) gneiss may be resolved into (1) a fundamental complex, composed mainly of gneisses that have affinities with plutonic igneous products, and to a limited extent of crystalline schists which may without doubt be regarded as of sedimentary origin; (2) a great series of

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igneous rocks intrusive in the fundamental complex in the form of dykes and sills.[1]

The rocks of the fundamental complex which have affinities with plutonic igneous products occupy the greater part of the tract between Cape Wrath and Skye. Mr. Teall has shown that they are essentially composed of minerals that enter into the composition of peridotites, gabbros, diorites, and granites; as, for example, olivine, hypersthene, augite (including diallage), hornblende, biotite, plagioclase, orthoclase, microcline, and quartz. In 1894 he advanced a classification of these rocks, based mainly on their mineralogical composition and partly on their structure, which has the great merit of being clear, comprehensive, and independent of theoretical views as to the history of the rock-masses. Stated broadly, the principle forming the basis of classification of three of the groups is the nature of the dominant ferro-magnesian constituent, viz., pyroxene, hornblende, or biotite, while the members of the fourth group are composed of ferro-magnesian minerals without felspar or quartz.[2] The detailed mapping of the region has shown that these rock-groups have a more or less definite geographical distribution. Hence the belt of Lewisian gneiss has been divided into three districts, the first extending from Cape Wrath to Loch Laxford, the second from near Scourie to beyond Lochinver, and the third from Gruinard Bay to the island of Raasay. In the central area (Scourie to Lochinver) pyroxene gneisses and ultrabasic rocks (pyroxenites and hornblendites) are specially developed, while the granular hornblende rocks (hornblende gneiss proper) and the biotite gneisses are characteristic of the northern and southern tracts. These are the facts, whatever theory be adopted to explain them.

In those areas where the original structures of the Lewisian gneiss have not been effaced by later mechanical stresses it is possible to trace knots, bands, and lenticles of unfoliated, ultrabasic, and basic rocks, to note the imperfect separation of the ferro-magnesian from the quartzo-felspathic constituents, to observe the gradual development of mineral banding and the net-like ramification of acid veins in the massive gneisses. Many of these rocks cannot be appropriately described as gneiss. Indeed, Mr. Teall has called attention to the close analogy between these structures and those of plutonic masses of younger date.

In the Report on Survey Work in the North-West Highlands published in 1888, the parallel banding, or first foliation, as it was then termed, of these original gneisses was ascribed to mechanical movement.[3] But the paper on "Banded Structure of Tertiary Gabbros in Skye," by Sir A. Geikie and Mr. Teall,[4] throws fresh light on this question. In that region the gabbro displays the alternation of acid and basic folia, the crumpling and folding of the bands like the massive gneisses of the Lewisian complex. Obviously in the Skye gabbro the structures cannot be due to subsequent earth-movements and deformation. The authors maintain that they are original structures of the molten magma, and, consequently, that much of the mineral banding of the Lewisian gneisses, as distinguished from foliation, may be due to the conditions under which the igneous magma was erupted and consolidated. Whatever theory be adopted to explain the original mineral banding of the Lewisian gneisses,

[1] Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland, based on the field-notes and maps of Messrs. B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. W. Hinxman, and H. M. Cadell: Quart. Journ. Geol. Soc., vol. xliv, p. 387; and Ann. Rep. Geol. Surv., 1894, p. 280, and 1895, p. 17.

[2] Ann. Rep. Geol. Surv., 1894, p. 280.

[3] Quart. Journ. Geol. Soc., vol. xliv, p. 400.

[4] Ibid., vol. L, p. 645.

it is certain that they possessed this banding, and were thrown into gentle folds before the uprise of the later intrusive dykes.

The crystalline schists that have affinities with rocks of sedimentary origin occupy limited areas north of Loch Maree and near Gairloch. The prominent members of this series are quartz schists, mica schists, graphitic schists, limestones and dolomites with tremolite, garnet and epidote.[1] They are there associated with a massive sill of epidiorite and hornblende schist. The relations which these altered sediments bear to the gneisses that have affinities with plutonic igneous products have not been satisfactorily determined. But the detailed mapping has proved that north of Loch Maree they rest on a platform of Lewisian gneiss, and are visibly overlain by gneiss with basic dykes (Meall Riabhach), and that both the gneiss complex and altered sediments have been affected by a common system of folds. In the field, bands of mylonized rock have been traced near the base of the overlying cake of gneiss, and the microscopic examination of the latter by Mr. Teall has revealed cataclastic structures due to dynamic movement. It is obvious, therefore, that, whatever may have been the original relations of the altered sediments to the gneiss complex, these have been obscured by subsequent earth-stresses.

The great series of later igneous rocks which pierce the fundamental complex in the form of dykes and sills is one of the remarkable features in the history of the Lewisian gneiss. In 1895 Mr. Teall advanced a classification of them,[2] but his recent researches show that they are of a much more varied character. For our present purpose we may omit the dykes of peculiar composition and refer to the dominant types. These comprise: (1) ultrabasic rocks (peridotite), (2) basic (dolerite and epidiorite, and (3) acid (granite and pegmatite). The evidence in the field points to the conclusion that the ultrabasic rocks cut the basic, and that the granite dykes were intruded into the gneisses after the eruption of the basic dykes. The greater number of these dykes consists of basic materials. It is important to note that the basic rocks best preserve their normal dyke-like features in the central tract between Scourie and Lochinver, where they traverse the pyroxene gneisses. But southwards and northwards of that tract, in districts where they have been subjected to great dynamic movement, they appear as bands of hornblende schist, which are difficult to separate from the fundamental complex. The acid intrusions are largely developed in the northern tract between Laxford and Durness; indeed, at certain localities in that region the massive and foliated granite and pegmatite are as conspicuous as the biotite gneisses and hornblende gneisses with which they are associated.

After the eruption of the various intrusive dykes the whole area was subjected to enormous terrestrial stresses, which profoundly affected the fundamental complex and the dykes which traverse it. These lines of movement traverse the Lewisian plateau in various directions, producing planes of disruption, molecular rearrangement of the minerals, and the development of foliation. It seems to be a general law that the new planes of foliation both in the gneiss and dykes are more or less parallel with the planes of movement or disruption. If the latter be vertical or nearly horizontal the inclination of the foliation planes is found to vary accordingly.

Close to the well-defined disruption planes, like those between Scourie and Kylesku, the gneiss loses its low angle, and is thrown into sharp folds, the axes of which are parallel with the planes of movement. The folia

[1] Ann. Rep. Geol. Surv., 1895, p. 17.
[2] Ibid., p. 18.

are attenuated, there is a molecular rearrangement of the minerals, and the resultant rock is a granulitic gneiss. Indeed, the evidence in the field, which has been confirmed by the microscopic examination of the rocks by Mr. Teall, seems to show that granulitic biotite and hornblende gneisses are characteristic of the zones of secondary shear. A further result of these earth-stresses is the plication of the original gneisses in sharp folds, trending N.W. and S.E. and E. and W., and the partial or complete recrystallization of the rocks along the old planes of mineral banding.

In like manner, when the basic dykes are obliquely traversed by lines of disruption, they are deflected, attenuated, and within the shear zones appear frequently as phacoidal masses amid the reconstructed gneiss. These phenomena are accompanied by the recrystallization of the rock and its metamorphosis into hornblende schist. Similar results are observable when the lines of movement are parallel with the course of the dykes. All the stages of change from the massive to the schistose rock can be traced—the replacement of the pyroxene by hornblende, the conversion of the felspar, and the development of granulitic structure with foliation. Here we have an example of the phenomena developed on a larger scale by the Post-Cambrian movements, viz., the production of common planes of schistosity in rocks separated by a vast interval of time, quite irrespective of their original relations. For both gneiss and dykes have common planes of foliation, resulting from earth-stresses in Pre-Torridonian time.

It is important to note also that linear foliation is developed in the basic dykes where there has been differential movement of the constituents in folded areas. In the case of the anticline mapped by Mr. Clough, near Poolewe in Ross-shire, he has shown that the linear foliation is parallel with the pitch of the folds. All these phenomena tend to confirm the conclusions arrived at by Mr. Teall, and published in his well-known paper "On the Metamorphosis of Dolerite into Hornblende Schist." [1]

The ultrabasic and acid rocks likewise occur in the schistose form, for the peridotites pass into talcose schists and the granite becomes gneissose.

In connection with the development of schistosity in these later intrusive rocks it is interesting to observe that where the basic dykes merge completely into hornblende schist, and seem to become an integral part of the fundamental complex, biotite gneisses and granular hornblende gneisses prevail. Whatever be the explanation the relationship is suggestive.

The unconformability between the Lewisian gneiss and the overlying Torridon Sandstone, which was noted by Macculloch and confirmed by later observers, must represent a vast lapse of time. When tracing this base-line southwards through the counties of Sutherland and Ross, striking evidence was obtained by the Geological Survey of the denudation of that old land surface. In the mountainous region between Loch Maree and Loch Broom it has been carved into a series of deep narrow valleys with mountains rising to a height of 2,000 feet. In that region it is possible to trace the orientation of that buried mountain chain and the direction of some of the old river courses. This remnant of Archæan topography must be regarded as one of the remarkable features of that interesting region.

In 1893 the various divisions of the Torridon Sandstone, as developed between Cape Wrath and Skye, were tabulated by the Geological Survey, and may here be briefly summarized. They form three groups : a lower, composed of epidotic grits and conglomerates, dark and grey shales

[1] Quart. Journ. Geol. Soc., vol. xli, p. 133.

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with calcareous bands, red sandstones, and grits; a middle, consisting of a great succession of false-bedded grits and sandstones; an upper, comprising chocolate-coloured sandstone, micaceous flags with dark shales and calcareous bands. The total thickness of this great pile of sedimentary deposits must be upwards of 10,000 feet, and if Mr. Clough's estimate of the development of the lower group in Skye be correct, this amount must be considerably increased. Of special interest is the evidence bearing on the stratigraphical variation of the Torridon Sandstone when traced southwards across the counties of Sutherland and Ross. The lower group is not represented in the northern area, but southwards, in Ross-shire, it appears, and between Loch Maree and Sleat varies from 500 to several thousand feet in thickness. These divisions of the Torridon Sandstone are of importance in view of the correlation of certain sediments in Islay with the middle and lower Torridonian groups which there rest unconformably on a platform of Lewisian gneiss.

In continuation of the researches of Dr. Hicks, published in his paper "On Pre-Cambrian Rocks occurring as Fragments in the Cambrian Conglomerates in Britain,"[1] Mr. Teall has specially investigated the pebbles found in the Torridon Sandstone. The local basement breccias of that formation have doubtless been derived from the platform of Lewisian gneiss on which they rest, but the pebbles found in the coarse arkose tell a different story.[2] He has found that they comprise quartzites showing contact alteration, black and yellow cherts, jaspers with spherulitic structures which indicate that they have been formed by the silicification of liparites of the 'Lea-rock' type and spherulitic felsites that bear a striking resemblance to those of Uriconian age in Shropshire. These interesting relics have been derived from formations which do not now occur anywhere in the western part of the counties of Sutherland and Ross, and they furnish impressive testimony of the denudation of the Archæan plateau in Pre-Torridonian time.

These Torridonian sediments, like the sandstones of younger date, contain lines of heavy minerals, such as magnetite, ilmenite, zircon, and rutile.[3] The dominant felspar of the arkose group is microcline, that of the basal group oligoclase. In the calcareous sediments of the upper and lower groups fossils might naturally be expected, but the search so far has not been very successful. Certain phosphatic nodules have been found in dark micaceous shales of the upper group which have been examined by Mr. Teall. From their chemical composition these nodules might be regarded as of organic origin; but he has found that they contain spherical cells with brown-coloured fibres, which appear to be débris of organisms.[4]

Early in last century the Torridonian deposits were referred by Macculloch[5] and Hay Cunningham[6] to the 'Primary Red Sandstone,' and by Murchison,[7] Sedgwick, and Hugh Miller to the Old Red Sandstone. The structural relations of the Torridon Sandstone to the overlying series of quartzites and limestones were first clearly shown by Professor Nicol,[8] who traced the unconformability that separates them for 100 miles across the counties of Sutherland and Ross. When Salter pointed out the Silurian facies of the fossils found in the Durness Limestone by Mr. Charles Peach, the Torridonian formation was correlated with the Cambrian rocks

[1] Geol. Mag., Dec. III, Vol. VII (1890), p. 516.
[2] Ann. Rep. Geol. Surv., 1895, p. 20.
[3] Ann. Rep. Geol. Surv., 1893, p. 263.
[4] Ibid., 1899, p. 185.
[5] Trans. Geol. Soc., ser. I, vol. ii, p. 450; "The Western Isles of Scotland," vol. ii, p. 89.
[6] Trans. Highland and Agricultural Society of Scotland, vol. xiii (1839).
[7] Trans. Geol. Soc., ser. II, vol. iii, p. 155.
[8] Quart. Journ. Geol. Soc., vol. xiii, p. 17.

of Wales by Murchison.[1] The discovery of the *Olenellus* fauna, indicating the lowest division of the Cambrian system, in the quartzite-limestone series by the Geological Survey in 1891[2] demonstrated the Pre-Cambrian age of the Torridon Sandstone. In view of that discovery, which proves the great antiquity of the Torridonian sediments, it is impossible to climb those picturesque mountains in Assynt or Applecross without being impressed with the unaltered character of these deposits. Yet it can be shown that under the influence of Post-Cambrian movements they approach the type of crystalline schists.

Before proceeding to the consideration of the Durness series of quartzites and limestones and their relations to the Eastern Schists, brief reference must be made to the controversy between Murchison and Nicol regarding the sequence of the strata.

The detailed mapping of the belt between Eriboll and Skye by the Geological Survey has completely confirmed Nicol's conclusions (1) that the limestone is the highest member of the Durness series; (2) that the so-called 'Upper Quartzite' and 'Upper Limestone' of Murchison's sections are merely the repetition of the lower quartzite and limestone due to faults or folds; (3) that there is no conformable sequence from the quartzites and limestones into the overlying schists and gneiss; (4) that the line of junction is a line of fault indicated by proofs of fracture and contortion of the strata. It is true that in the course of his investigations Nicol's views underwent a process of evolution, and that even in the form in which he ultimately presented them he did not grasp the whole truth. We now know that he was in error when he regarded portions of the Archæan gneiss, occurring in the displaced masses, as igneous rocks intruded during the earth-movements, and that he failed to realize the evidence bearing on dynamic metamorphism resulting from these movements. But I do not doubt that the verdict of the impartial historian will be that Nicol displayed the qualities of a great stratigraphist in grappling with the tectonics of one of the most complicated mountain chains in Europe.

The period now under review embraces the reopening of that controversy in 1878 by Dr. Hicks, and its close in 1884 after the publication of the "Report on the Geology of the North-West of Sutherland" by the Geological Survey.[3] The Survey work has confirmed Professor Bonney's identification of the Lewisian gneiss and Torridon Sandstone in Glen Logan, Kinlochewe,[4] brought into that position by a reversed fault; and Dr. Callaway's conclusions regarding overthrust faulting at Loch Broom, in Assynt and in Glencoul.[5] Special reference must be made to the remarkable series of papers by Professor Lapworth on "The Secret of the Highlands," in which he demonstrated the accuracy of Nicol's main conclusions, and pointed out that the stratigraphical phenomena are but the counterpart of those in the Alps as described by Heim.[6] His researches, moreover, led him to a departure from Professor Nicol's views regarding the age, composition, and mode of formation of the Eastern Schists, for in the paper which he communicated to the Geologists' Association in 1884 he announced that their present foliated and mineralogical characters had been developed by the crust-movements which operated in that region since the time of the Durness quartzites and limestones.[7] Allusion must

[1] Ibid., vol. xv, p. 353.
[2] Ibid., vol. xlviii, p. 227.
[3] *Nature*, vol. xxxi, p. 29, November, 1884.
[4] Quart. Journ. Geol. Soc., vol. xxxvi, p. 93.
[5] Ibid., vol. xxxix, p. 416.
[6] Geol. Mag., Dec. II, Vol. X (1883), pp. 120, 193, 337.
[7] Proc. Geol. Assoc., vol. viii, p. 438; Geol. Mag., Dec. III, Vol. II (1885), p. 97.

be made also to his great paper "On the Discovery of the *Olenellus* Fauna in the Lower Cambrian Rocks of Britain," in which he not only chronicled the finding of this fauna at the top of the basal quartzite in Shropshire, but suggested the correlation of the Durness quartzites and limestones with the Cambrian rocks elsewhere.[1] That suggestion was strikingly confirmed within three years afterwards by the discovery of the *Olenellus* fauna in Ross-shire.

The detailed mapping of the belt of Cambrian strata has proved the striking uniformity of the rock sequence. There is little variation in the lithological characters or thicknesses of the various zones. Basal quartzites, pipe-rock, Fucoid-beds, Serpulite (*Salterella*) grit, limestone, and dolomite form the invariable sequence, for a distance of a hundred miles, to the west of the line of earth-movements. This feature is also characteristic of the fossiliferous zones, for the sub-zones of the pipe-rock, the *Olenellus* fauna in the Fucoid-beds, and the *Salterella* limestone have been traced from Eriboll to Skye. Owing to the interruption of the sequence by reversed faults or thrusts, the higher fossiliferous limestone zones are never met with between Eriboll and Kishorn, but they occur in Skye, where they were first detected by Sir A. Geikie.[2]

Regarding the palæontological divisions of the system, my colleague, Mr. Peach, concludes "that the presence of three species of *Olenellus* in the Fucoid-beds and Serpulite grit of the North-West Highlands, nearly allied to the American form *Olenellus Thomsoni*—the type species of the genus—together with *Hyolithes*, *Salterella*, and other organisms found with it, prove that these beds represent the Georgian terrane of America, which, as shown by Walcott, underlies the *Paradoxides* zone." Hence he infers that there can be no doubt of the Lower Cambrian age of the beds yielding the *Olenellus* fauna in the North-West Highlands. Mr. Peach further confirms Salter's opinion as to the American facies of the fossils obtained from the higher fossiliferous zones of the Durness dolomite and limestone. He states that "the latter fauna is so similar to, if not identical with, that occurring in Newfoundland, Mingan Islands, and Point Levis, beneath strata yielding the *Phyllograptus* fauna of Arenig age, that the beds must be regarded as belonging to the higher divisions of the Cambrian formation."

The intrusive igneous rocks of the Assynt region, of later date than Cambrian time, and yet older than the Post-Cambrian movements, have been specially studied by Mr. Teall, who has obtained results of special importance from a petrological point of view. This petrographical province embraces the plutonic complex of Cnoc na Sroine and Loch Borolan, and the numerous sills and dykes that traverse the Cambrian and Torridonian sediments, and even the underlying platform of Lewisian gneiss. He infers that the plutonic rocks have been formed by the consolidation of alkaline magmas rich in soda. At the one end of the series is the quartz-syenite of Cnoc na Sroine, and at the other the basic augite-syenite, nepheline-syenite, and borolanite. The basic varieties occur on the margin, and the acid varieties in the centre. The sills and dykes comprise two well-marked types, camptonites or vogesites, and felsites with alkali felspar and ægirine, which he believes to represent the dyke form of the magmas that gave rise to the plutonic mass.[3]

The striking feature in the geology of the North-West Highlands is the evidence relating to those terrestrial movements that affected that region in Post-Cambrian times, which are without a parallel in Britain. The geological structures produced by these displacements are extremely complicated, but the vast amount of evidence obtained in the course of the

[1] Geol. Mag., Dec. III, Vol. V (1888), pp. 484–487.
[2] Quart. Journ. Geol. Soc., vol. xliv, p. 62.
[3] Geol. Mag., Dec. IV, Vol. VII (1900), p. 385.

survey of that belt clearly proves that, though the sections vary indefinitely along the line of complication, they have certain features in common which throw much light on the tectonics of that mountain chain. Some of these features may thus be briefly summarized :—

1. By means of lateral compression or earth-creep the strata are thrown into a series of inverted folds which culminate in reversed faults or thrusts.

2. Without incipient folding, the strata are repeated by a series of minor thrusts or reversed faults which lie at an oblique angle to the major thrust-planes and dip in the direction from which the pressure came, that is, from the east.

3. By means of major thrusts of varying magnitude the following structures are produced : (*a*) the piled-up Cambrian strata are driven westwards along planes formed by the underlying undisturbed materials; (*b*) masses of Lewisian gneiss, Torridon Sandstone, and Cambrian rocks are made to override the underlying piled-up strata; (*c*) the Eastern Schists are driven westwards and, in some cases, overlap all major and minor thrusts till they rest directly on the undisturbed Cambrian strata.

When to these features are added the effects of normal faulting and prolonged denudation, it is possible to form some conception of the evolution of those extraordinary structures which are met with in that region. Some of the features just described occur in other mountain chains affected by terrestrial movement, as in the Alps and in Provence; but there is one which appears to be peculiar to the North-West Highlands. It is the remarkable overlap of the Moine Thrust-plane—the most easterly of the great lines of displacement. Along the southern confines of the wild and complicated region of Assynt, that plane can be traced westwards for a distance of six miles to the Knockan cliff, where the micaceous flagstones rest on the Cambrian Limestone. In Durness we find an outlier of the Eastern Schists reposing on Cambrian Limestone, there preserved by normal faults, at a distance of about ten miles from the mass of similar schists east of Loch Eriboll, with which it was originally continuous.

Though many of these structures appear incredible at first, it is worthy of note that some have been reproduced experimentally by Mr. Cadell.[1] He took layers of sand, loam, clay, and plaster of Paris, and after the materials had set into hard brittle laminæ, in imitation of sedimentary strata, he applied horizontal pressure under varying conditions. The results, some of which may here be given, were remarkable.

1. The compressed mass tends to find relief along a series of gently inclined thrust-planes, which dip towards the side from which pressure is exerted.

2. After a certain amount of heaping up along a series of minor thrust-planes, the heaped-up mass tends to rise and ride forward bodily along major thrust-planes.

3. The front portion of a mass being pushed along a thrust-plane tends to bend over and curve under the back portion.

4. A thrust-plane below may pass into an anticline above; and a major thrust-plane above may and probably always does originate in a fold below.

Now these important experiments confirm the conclusion reached by the Geological Survey from a study of the phenomena in the field, viz., that under the influence of horizontal compression or earth-creep the rocks in that region behaved like brittle rigid bodies which snapped across, were piled up, and driven westwards in successive slices. But, further, these displacements were accompanied by differential movement of the materials which resulted in the development of new structures. These phenomena culminate along the belt of rocks in immediate association with the Moine

[1] Trans. Roy. Soc. Edinburgh, vol. xxxv, p. 337.

Thrust, where the outcrop of that thrust lies to the east of a broad belt of displaced materials. There, Lewisian gneiss, Torridon Sandstone, and Cambrian quartzite are sheared and rolled out, presenting new divisional planes parallel with that of the Moine Thrust. The Lewisian gneiss shades into flaser gneiss and schist, and ultimately passes into a banded rock like a platy schist. The pegmatites show fluxion structure with felspar 'eyes' like that of the rhyolites. At intervals in these zones of highly sheared rocks, phacoidal masses of Lewisian gneiss appear, in which the Pre-Torridonian structures are not wholly effaced. The sills of camptonite and felsite intrusive in the Cambrian rocks become schistose, and together with the sediments in which they occur appear in a lenticular form. All these mylonized rocks show a characteristic striping on the divisional planes, due to orientation of the constituents in the direction of movement.

Still more important evidence in relation to the question of regional metamorphism is furnished by the Torridon Sandstone. In the case of the basal conglomerate the pebbles have been flattened and elongated, and a fine wavy structure has been developed in the matrix. In the district of Ben More, Assynt, planes of schistosity, more or less parallel with the planes of the Ben More Thrust, pass downwards from the Torridon conglomerate into the underlying gneiss. Both have a common foliation irrespective of the unconformability between them. Again, along the great inversion south of Stromeferry, foliation has been developed in the Torridon conglomerate and overlying Lewisian gneiss, parallel to the plane of the Moine Thrust. The Torridon grits and sandstones south of Kinlochewe and between Kishorn and Loch Alsh are similarly affected by the Post-Cambrian movements. Mr. Teall has shown that the quartz grains have been drawn out into lenticles and into thin folia that wind round 'eyes' of felspar. A secondary crypto-crystalline material has been produced, sericitic mica appears in the divisional planes, and in some instances biotite is developed. In short, he concludes that in these deformed Torridonian sediments there is an approximation to the crystalline schists of the Moine type. The stratigraphical horizon of these rocks can be clearly proved. The subdivisions of the Torridon Sandstone have been recognized in those displaced masses which lie to the east of the Kishorn Thrust and to the west of the Moine Thrust. It is worthy of note also that in the belt of highly sheared gneiss south of Stromeferry that comes between the Torridonian inversion in the west and the Moine Thrust on the east Mr. Peach has found folded and faulted inliers of the basal division of the Torridon Sandstone that have a striking resemblance to typical Moine schists.

Regarding the age of these Post-Cambrian movements, it is obvious that they must be later than the Cambrian Limestone and older than the Old Red Sandstone, for the basal conglomerates of the latter rest unconformably on the Eastern Schists, and contain pebbles of basal quartzite, pipe-rock, limestone, and dolomite derived from the Cambrian rocks of the North-West Highlands.

East of the Moine Thrust or great line of displacement extending from Eriboll to Skye, we enter the wide domain of the metamorphic rocks of the Highlands, a region now under investigation, and which presents difficult problems for solution. Two prominent types of crystalline schists (Caledonian series, Callaway, and Moine schists of the Geological Survey) have been traced over wide areas in the counties of Sutherland, Ross, and Inverness, and across the Great Glen to the northern slopes of the Grampians. Consisting of granulitic quartzose schists and muscovite-biotite schist or gneiss, they appear to be of sedimentary origin, though crystalline. They are associated with recognizable masses of Lewisian

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gneiss covering many square miles of ground and presenting many of the structures so characteristic of that complex in the undisturbed areas already described. Within the belt of Lewisian gneiss at Glenelg Mr. Clough has mapped a series of rocks presumably of sedimentary origin, including graphitic schists, mica schists, and limestones, but the gneiss with which they are associated possesses granulitic structure like that of the adjoining Moine schists.[1] Further, in the east of Sutherland, and also in the county of Ross, foliated and massive granites appear which are interleaved in the adjoining Moine schists, forming injection gneisses and producing contact metamorphism.[2]

In the Eastern Highlands the Moine series disappears and is replaced by a broad development of schists, admittedly of sedimentary origin, which have been termed the Dalradian series by Sir A. Geikie. Within recent years it has been divided into certain rock-groups which have been traced by the Geological Survey from the counties of Banff and Aberdeen to Kintyre. It has been found that, though highly crystalline in certain areas, they pass along the strike into comparatively unaltered sediments, as proved by Mr. Hill in the neighbourhood of Loch Awe.[3] Before the planes of schistosity were developed in these Dalradian schists they were pierced by sills of basic rock (gabbro and epidiorite) and acid material (granite), both of which must have shared in the movements that affected the schists, as they merge respectively into hornblende schists and foliated granite or biotite gneiss. Both seem to have developed contact metamorphism; indeed, Mr. Barrow[4] contends that the regional metamorphism so prominent in the South-East Highlands is mainly, if not wholly, due to the intrusion of an early granite magma, now exposed at the surface in the form of local bosses of granite and isolated veins of pegmatite.

The age of the Dalradian schists has not been determined. Though there seems to be an apparent order of superposition, in this series it is still uncertain whether that implies the original sequence of deposition. Since Sir A. Geikie applied the term Dalradian to the Eastern Highland schists in 1891,[5] evidence has been obtained[6] that suggests the correlation of certain rocks along the Highland border with the Arenig and younger Silurian strata of the Southern Uplands. Consisting of epidiorite, chlorite schist, radiolarian cherts, black shales, grits, and limestone, they have been traced at intervals from Arran to Kincardineshire. In the latter region Mr. Barrow contends that they are separated by a line of disruption from the Highland schists to the north; but no such discordance has been detected in the Callander district or in Arran. Though these rocks of the Highland border have been much deformed, yet their occurrence in the same order of succession in that region and in the Southern Uplands is presumptive evidence for their correlation.

In view of this evidence it is not improbable that the Dalradian series may contain rock-groups belonging to different geological systems. Indeed, the result of recent Survey work in Islay tends to support this view. For in the south-west part of that island there is a mass of Lewisian gneiss overlaid unconformably by sedimentary strata which have been correlated with the lower and middle divisions of the Torridon Sandstone. Unfortunately the sequence ends here, as both the gneiss and overlying

[1] Summary of Progress Geol. Surv. 1897, p. 37.

[2] "On Foliated Granites and their Relations to the Crystalline Schists in Eastern Sutherland": Quart. Journ. Geol. Soc., vol. lii, p. 633.

[3] Ann. Rep. Geol. Surv., 1893, p. 265.

[4] "Intrusion of Muscovite-biotite Gneiss in the South-East Highlands and its accompanying Metamorphism": Quart. Journ. Geol. Soc., vol. xlix, p. 330.

[5] Quart. Journ. Geol. Soc., vol. xlvii, p. 72.

[6] Ann. Rep. Geol. Surv., 1893, p. 266; 1895, p. 25; 1896, p. 27.

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sediments are separated by a line of disruption or thrust-plane from the strata in the eastern part of the island. And yet, notwithstanding this break, the evidence obtained in the latter district is remarkable, whatever theory be adopted to explain it. There the Islay limestone and black slates appear to be covered unconformably by the Islay quartzite containing Annelid tubes and followed in ascending sequence by Fucoidal shales and dolomites, suggestive of the Cambrian succession in Sutherland and Ross. The Islay quartzite passes into Jura, thence to the mainland, and it may eventually prove to be the Perthshire quartzite, while the Islay limestone and black slate are supposed to be the prolongations of the limestone and slate of the Loch Awe series in Argyllshire.[1]

From the foregoing data it will be seen that much uncertainty prevails regarding the age and structural relations of the metamorphic rocks of the Highlands, but the difficulties that here confront the observer are common to all areas affected by regional metamorphism.

A prominent feature in the geology of the Eastern Highlands is the great development of later plutonic rocks chiefly in the form of granite ranging along the Grampian chain from Aberdeenshire to Argyllshire. In connection with one of these masses a remarkable paper appeared in 1892 which in my opinion has profoundly influenced petrological inquiry in Scotland from the light which it threw on the relations of a connected series of petrographical types in a plutonic complex. I refer to the paper on the "Plutonic Rocks of Garabal Hill and Meall Breac," by Mr. Teall and Mr. Dakyns.[2]

The authors showed that this plutonic mass comprises granite, tonalite, augite-diorite, picrites, serpentine, and other compounds. Mr. Teall regards the members of this sequence as products of one original magma by a process of differentiation, the peridotites being the oldest rocks, because the minerals of which they are composed are the first to form in a plutonic magma. As the process of consolidation advances, rocks of a varied composition arise, in the order of increasing acidity, viz., diorites, tonalites, and granites. The most acid rock consists of quartz and orthoclase, which may represent the mother liquor after the other constituents had separated out. Mr. Teall concludes that progressive consolidation of one reservoir gives rise to the formation of magmas of increasing acidity, and hence that basic rocks should precede the acid rocks. This theory of magmatic differentiation—so strenuously advocated by Brögger, Vogt, Rosenbusch, Iddings, Teall, and others—was first applied to the interpretation of varied types of plutonic masses in Scotland by Mr. Teall in the paper referred to. Since then he has extended its application to the granite masses in the Silurian tableland of the south of Scotland, which include rocks ranging from hyperites at the one end to granitite with microcline and aplite veins at the other.[3] Many of the phenomena presented by the newer granite masses of the Eastern Highlands seem to lend support to this theory. These views, indeed, have permeated the petrological descriptions of the granitic protrusions in the counties of Aberdeen and Argyll which have been given by Messrs. Barrow, Hill, Kynaston, and Craig[4] in recent years.

One of the remarkable advances in Scottish geology during the period under review is the solution of the order of succession and tectonic

[1] Summary of Progress Geol. Surv. 1899, p. 66.

[2] Quart. Journ. Geol. Soc., vol. xlviii, p. 104.

[3] Ann. Rep. Geol. Surv., 1896, p. 40; see also "The Silurian Rocks of Scotland," Geol. Surv. Memoir, 1899, p. 607.

[4] Ann. Rep. Geol. Surv., 1897, p. 87; 1898, pp. 25–28. See also paper on "Kentallenite and its Relations to other Igneous Rocks in Argyllshire": Quart. Journ. Geol. Soc., vol. lvi, p. 531.

relations of the Silurian rocks of the south of Scotland by Professor Lapworth. The history of research relating to that tableland, and of all his contributions to the problems connected with it, has been given in detail in the recent volume of the Geological Survey on that formation. At present it will be sufficient to refer to his three classic papers, which, in my opinion, record one of the great achievements in British geology. The first, on "The Moffat Series,"[1] demonstrated, by means of the vertical distribution of the graptolites, the order of succession in those fine deposits (black shales and mudstones), which were laid down near the verge of sedimentation, and are now exposed in anticlinal folds in the central belt. The second, on "The Girvan Succession,"[2] showed how certain graptolite zones of the Moffat shales are interleaved, in the Girvan region, with conglomerates, grits, sandstones, flagstones, mudstones, shales, and limestones, charged with all the varied forms of life found in shallow seas or near shore. In the third, on "The Ballantrae Rocks of the South of Scotland and their Place in the Upland Sequence,"[3] he indicated the distribution and variation of the Moffat terrane (Upper Llandeilo to Upper Llandovery) and of the Gala terrane (Tarannon), which form the greater part of the uplands. He further pointed out how the rocks and the fossils vary across the uplands according to the conditions of deposition. Finally, he proved that the complicated tectonics of the Silurian tableland, its endless overfolds, its endoclinal and exoclinal structures, can be unravelled by means of the graptolite zones. These researches disposed of the order of succession based on Barrande's doctrine of Colonies, and established the zonal value of graptolites as an index of stratigraphical horizons. So complete was the zonal method of mapping adopted by Professor Lapworth, and so accurate were his generalizations, that few modifications have been made in his work.

In the course of the re-examination of the Silurian tableland by the Geological Survey some important additions were made to our knowledge of the Silurian system as there developed. Underlying all the sediments of the uplands there is a series of volcanic and plutonic rocks of Arenig age, the largest development of which occurs at Ballantrae in Ayrshire, where their igneous character was recognized by Professor Bonney. But they appear in the cores of numerous anticlines over an area of about 1,500 square miles, forming one of the most extensive volcanic areas of Palæozoic age in the British Isles. These volcanic rocks are overlain by a band of cherts and mudstones, succeeded by black shales yielding Glenkiln graptolites of Upper Llandeilo age. The cherts, which are abundantly charged with Radiolaria, implying oceanic conditions of deposition, are about 70 feet thick, and have been traced over an area of about 2,000 square miles. The deposition of the Radiolarian ooze must have occupied a long lapse of time. Indeed, the cherts and mudstones represent the strata which, in other regions, form the Upper Arenig and Lower Llandeilo divisions of the Silurian system. They furnish interesting evidence of the oceanic conditions which here prevailed in early Silurian time, and form a natural sequel to Professor Lapworth's researches bearing on the graptolitic deposits of the Upper Llandeilo period, which must have been laid down on the sea-floor near the limit of the land-derived sediment.

Of special interest is the new fish fauna found by the Geological Survey in the Ludlow and Downtonian rocks between Lesmahagow and Muirkirk, which the researches of Dr. Traquair have shown to be of great biological and palæontological value.[4] This discovery has enabled

[1] Quart. Journ. Geol. Soc., vol. xxxiv, p. 240.
[2] Ibid., vol. xxxviii, p. 537.
[3] Geol. Mag., Dec. III, Vol. VI (1889), p. 20.
[4] Trans. Roy. Soc. Edinb., vol. xxxix, p. 827.

him to give a new classification of the Ostracodermi, and to enlarge the order of the Heterostraci, which now includes four families, instead of the Pteraspidæ alone. He has further shown that the Cœlolepidæ were not Cestraciont sharks to which the *Onchus* spines belonged, but Heterostraci, though probably of Elasmobranch origin, judging from the shagreen-like scales. The Cœlolepidæ are common fishes in the Ludlow and Downtonian rocks of Lanarkshire. The genus *Thelodus*, first described by Agassiz from detached scales in the Ludlow bone-bed, and subsequently figured and described by Pander and Rohon from scales in the Upper Silurian rocks of Oesel, is here represented for the first time by nearly complete forms. But it is remarkable that no *Onchus* spines, nor any Pteraspidæ, nor Cephalaspidæ have been found in the Lanarkshire strata, the nearest related genus to *Cephalaspis* being *Ateleaspis*, which, however, represents a distinct family.

The group of sandstones, conglomerates, shales, and mudstones that form the passage-beds between the Ludlow rocks and the Lower Old Red Sandstone in Lanarkshire are now regarded as the equivalents of the Downtonian strata in Shropshire, and are linked with the Silurian system. The mudstones of this group, containing the new fish fauna, likewise yield ostracods, phyllocarid crustaceans, and eurypterids—forms which connect these beds with the underlying Ludlow rocks. The band of greywacke-conglomerate, that extends from the Pentland Hills into Ayrshire, composed largely of pebbles derived from the Silurian tableland, is now taken as the base-line of the Lower Old Red Sandstone on the south side of the great midland valley of Scotland.

The period under review has been marked by important additions to our knowledge of the Old Red Sandstone formation. In 1878 appeared a valuable monograph by Sir Archibald Geikie on "The Old Red Sandstone of Western Europe,"[1] by far the most important treatise on this subject since the publication of Hugh Miller's classic work in 1841. Following up the view maintained by Fleming, Godwin-Austen, and Ramsay, that the deposits of this formation were laid down in lakes or inland seas, he defined the geographical areas of the various basins in the British area, giving to each a local name. He gave an outline of the development of the rocks north of the Grampians in Caithness, Orkney, and Shetland. He advanced an ingenious argument in favour of correlating the Caithness flagstone series (middle division, Murchison) with the Lower Old Red Sandstone south of the Grampians. He contended that "the admitted palæontological distinctions between the two areas are probably not greater than the striking lithological differences between the strata would account for, or than the contrast between the ichthyic faunas of adjacent but disconnected water basins at the present time." Sir A. Geikie further gave a table showing the vertical range of the known fossils of the Caithness series from data partly supplied by the late Mr. C. Peach.

During the last quarter of a century Dr. Traquair has made a special study of the ichthyology of the Old Red Sandstone and Carboniferous strata of Scotland, which has enabled him to throw much light on the distribution of fossil fishes in these rocks and on their value for the purpose of correlation. His researches show that the fish fauna of the formation south of the Grampians resembles that of the Lower Old Red Sandstone of the West of England and adjoining part of Wales in the abundance of specimens of *Cephalaspis*, the common species in Forfarshire (*C. Lyelli*, Ag.) being also indistinguishable from that in the Herefordshire beds. *Pteraspis* occurs in both regions, though of different species. Of Acanthodians *Parexus recurvus*, Ag., occurs in both, together with

[1] Trans. Roy. Soc. Edinb., vol. xxviii, p. 345.

Climatius (*C. ornatus*, Ag.). The abundance of *Cephalaspis* (*C. Campbelltonensis*, Whit., *C. Jexi*, Traq.) and of *Climatius* spines is characteristic of the Lower Devonian rocks of Canada.

The Old Red Sandstone of Lorne has recently yielded organic remains, akin to those found in Forfarshire, south of the Grampians, viz. *Cephalaspis Lornensis* (Traq.), and two species of myriapods (*Campecaris Forfarensis* and a species of *Archidesmus*).[1]

In the deposits of Lake Orcadie, north of the Grampians, quite a different fish fauna from that of Forfarshire appears. Dr. Traquair has noted that there are no species common to the two areas, and only two genera, viz. *Mesacanthus* and *Cephalaspis*. The latter genus is, however, represented in Caithness only by a single specimen of a species (*C. magnifica*, Traq.) different from any found elsewhere. It might here be observed that *Cephalaspis* is represented also in the Upper Devonian rocks of Canada by a single specimen of a peculiar species (*C. laticeps*, Traq.), and hence Dr. Traquair has shown that, though *Cephalaspis* is most abundant in the Lower Devonian, it extends also into the upper division of that system. It further appears that Osteolepidæ (*Osteolepis*, *Diplopterus*), Rhizodontidæ (*Tristichopterus*, *Gyroptychius*), Holoptychiidæ (*Glyptolepis*), Asterolepidæ (*Pterichthys*, *Microbrachius*), Ctenodontidæ (*Dipterus*) are abundant in the Orcadian fauna, none of which has occurred in the Lower Old Red Sandstone of Forfarshire, the West of England, or in the Lower Devonian rocks of Canada. Dr. Traquair recognized, however, the identity of the fishes from the well-known fish band in the basin of the Moray Firth with those brought from the west part of Orkney, though these forms did not quite agree with the fossils from the Thurso district. He subsequently found that the fish fauna from the Orcadian beds in the Moray Firth basin is represented in Caithness by that of Achanarras; and, further, that two other faunas occur in the Caithness area—that of Thurso and that of John o' Groats, as given below :—

John o' Groats	*Tristichopterus alatus*, Egert. *Microbrachius Dicki*, Traq.
Thurso	*Coccosteus minor*, H. Miller. *Thursius pholidotus*, Traq. *Osteolepis microlepidotus*, Pander.
Achanarras	*Pterichthys*, three species. *Cheirolepis Trailli*, Ag. *Osteolepis macrolepidotus*, Ag.

In 1898 appeared an important paper by Dr. Flett on "The Old Red Sandstone of the Orkneys,"[2] in which he described the results of his detailed examination of the islands. He proved the existence there of three fish faunas, and their correspondence with those identified in Caithness by Dr. Traquair. From the evidence in the field he adopted the following order of succession and correlation of the strata :—

3. Eday Sandstones and John o' Groats beds.
2. Rousay and Thurso beds.
1. Stromness, Achanarras, and Cromarty beds.

A further important result of Dr. Flett's researches in the Old Red Sandstone of these northern isles was communicated to the Royal Society of Edinburgh this year. He has found in the Shetland beds, which had previously yielded no fossils save plants, fragments, identified by Dr. Traquair as *Holonema*, a fish new to Britain, but occurring in the Chemung group of North America, the subdivision of the Upper Devonian that immediately underlies the Catskill red sandstones, with remains of

[1] Summary of Progress Geol. Surv. 1897, p. 83.
[2] Trans. Roy. Soc. Edinb., vol. xxxix, p. 383.

Holoptychius. Dr. Traquair has also recognized in Dr. Flett's collection fragments of *Asterolepis*, a genus characteristic of the Upper Old Red Sandstone, and which, as proved by Dr. Flett, occurs in the 'Thurso beds' of the Orkneys. The interest attaching to this discovery is very great, for Dr. Flett contends that it indicates a fourth life-zone in the Orcadian series, and, further, that it tends to span the break between the Orcadian division and Upper Old Red Sandstone.

In the Upper Old Red Sandstone on the south side of the Moray Firth, Dr. Traquair recognized two life-zones, and subsequently, with the assistance of Mr. Taylor, Lhanbryde, a third; in the following order. The lowest is that of the Nairn sandstones with *Asterolepis maxima* (Ag.); the second, that of Alves and Scaat Craig with *Bothriolepis major* (Ag.), *Psammosteus Taylori* (Traq.); and the highest, that of Rosebrae, the fauna of which, according to Dr. Traquair, has a striking resemblance to the assemblage in the Dura Den Sandstones in Fife.

Before 1876 all the Carboniferous areas in the great midland valley of Scotland had been mapped by the Geological Survey. The extent and structural relations of the various coalfields were determined according to the information then available, and shown in the published maps. But the rapid development of certain fields in the east of Scotland necessitated a revision of them, which has lately been done. The Fife Coalfield has been re-examined by Sir A. Geikie, Mr. Peach, and Mr. Wilson, and the oil-shale fields in the Lothians have been mapped by Mr. Cadell. An important memoir by Sir A. Geikie on "The Geology of Central and Western Fife and Kinross" has just been issued by the Geological Survey, in which the structure of these coalfields is described. Mr. Cadell lately gave an account of the geological structure of the oil-shale fields in his presidential address to the Edinburgh Geological Society.

Within the period under review detailed researches of great importance on the fossil flora of British Carboniferous rocks have been carried out by Mr. Kidston, to which reference ought to be made. The results are of the highest value for correlating the strata in different areas.[1] By means of the plants he arranges the Carboniferous rocks of Scotland in two great divisions: a lower, comprising the Calciferous Sandstone and Carboniferous Limestone series; and an upper, including the Millstone Grit and the Coal-measures, there being a marked palæontological break at the base of the Millstone Grit. He shows that the upper and lower divisions of the system, not only in Scotland but in Britain, are characterized by a different series of plants, not one species passing from the lower division, save in the case of *Stigmaria*, into the upper. From his researches it appears that, among ferns, *Neuropteris* is all but unknown in the lower division, whereas in the upper it is very abundant. The Sphenopterids are proportionately common in both divisions; but those of the lower are usually characterized by cuneate segments, while those of the upper have generally rounded pinnules. *Alethopteris*, so common throughout the whole of the upper series, is entirely absent from the lower. The genus *Calamites*, which is extremely plentiful in the upper, is almost entirely absent from the lower division, where its place is taken by *Asterocalamites*. The *Cordaiteæ* are also rare below the Millstone Grit, though very plentiful above that horizon. *Sigillaria*, so rare in the Lower Carboniferous rocks, is extremely abundant in the upper division, and particularly in the middle Coal-measures. In short, Mr. Kidston concludes that the floras of the two main divisions of the Carboniferous system, though belonging to the same types, are absolutely distinct in species and in the relative importance of the genera.

[1] "On the various Divisions of British Carboniferous Rocks as determined by their Fossil Flora": Proc. Roy. Phys. Soc. Edinb., vol. xii (1893), p. 183.

By means of the fossil plants Mr. Kidston correlates the Coal-measures of Scotland underlying the red sandstones with the lower division of the Coal-measures of England, and the overlying red sandstones of Fife with the middle division of the English Coal-measures.

It is remarkable that the evidence supplied by the fossil fishes has led Dr. Traquair independently to a similar conclusion. He holds that fossil ichthyology proves the existence of only two great life-zones in the Carboniferous rocks of Central Scotland—an upper and a lower—the boundary-line between the two being drawn at the base of the Millstone Grit. The Scottish Carboniferous rocks, being mostly estuarine, give an opportunity of comparing the estuarine fishes of both divisions. He finds the Coal-measure fishes of Scotland to be the same as those in the English Coal-measures, while those occurring below the Millstone Grit in Scotland are mostly different in species, and often, too, in genera, from the forms above that horizon.

Of special interest, as bearing on the former extension of this system in Scotland, is the discovery made by Professor Judd [1] in 1877 of a patch of Carboniferous sandstones and shales, with well-preserved plant remains in Morven. Another small outlier of this formation has recently been found in the Pass of Brander by the Geological Survey.[2]

The reptiles from the Elgin sandstones, recently described by Mr. E. T. Newton,[3] add fresh interest to the study of these rocks. The structural relations of these sandstones have been fully treated by Professor Judd in his great paper on the Secondary Rocks on the East of Scotland,[4] and again in his presidential address to this Section at Aberdeen,[5] who confirmed Huxley's well-known correlation of these beds with the Trias. The Dicynodont skull, identified by Professor Judd and Dr. Traquair at the Aberdeen meeting of the British Association in 1885, and other remains found in the reptilian sandstones in Cutties Hillock Quarry, where they rest on Upper Old Red Sandstone with *Holoptychius*, have been described by Mr. Newton. He confirmed their affinity with Dicynodonts, though they were referred to the genera *Gordonia* and *Geikia*. But the most remarkable specimen was the skull named by Mr. Newton *Elginia mirabilis*. This extraordinary creature, with a pair of horns projecting like those of a short-horned ox, and with smaller spines and bosses, numbering thirty-nine, is related to the great *Pareiasaurus* from the Karoo beds of South Africa. Two other reptiles are described by Mr. Newton from this quarry, namely, a small crocodile-like animal, *Erpetosuchus Granti*, apparently nearly allied to *Stagonolepis*, and *Ornithosuchus Woodwardi*, which is probably a small Dinosaurian.

Mr. Newton has raised an interesting point in connection with his researches. He calls attention to the fact that the reptilian remains from the Cutties Hillock Quarry differ from those found at other localities in the Elgin district. For example, the Lossiemouth sandstones have yielded *Stagonolepis*, *Hyperodapedon*, and *Telerpeton*; and the Cutties Hillock sandstones, the Dicynodonts (*Gordonia* and *Geikia*), the horned reptile (*Elginia*), the small crocodile-like *Erpetosuchus*, and the little Dinosaurian *Ornithosuchus*. Does this distribution indicate different stratigraphical horizons? is virtually the point raised by Mr. Newton. In connection with this inquiry he cites the evidence obtained in other countries. Thus, in the Gondwana beds of India, the series of reptiles similar to those of Elgin occur at different localities and on different

[1] Quart. Journ. Geol. Soc., vol. xxxiv, p. 685.
[2] Summary of Progress Geol. Surv. 1898, p. 129.
[3] Phil. Trans., vol. clxxxiv (1893), p. 431; ibid., vol. clxxxv (1894), p. 573.
[4] Quart. Journ. Geol. Soc., vol. xxix, p. 98.
[5] Rep. Brit. Assoc., 1885, p. 994.

stratigraphical horizons Dicynodonts and Labyrinthodonts being found in the lower Panchet rocks, while *Hyperodapedon* and *Parasuchus* (allied to *Stagonolepis*) are met with in the higher Kota-Maleri beds. Again, in the Karoo beds of South Africa the Dicynodonts and the great *Pareiasaurus*—the latter being the nearest known ally of the horned reptile (*Elginia mirabilis*) from Cutties Hillock, Elgin—occur low down in that formation. Further light is thrown on the question by the interesting discoveries of Amalitzky in Northern Russia, where a number of reptilian remains have been found closely allied to *Pareiasaurus*, *Elginia*, and *Dicynodon*, in beds which are referred to the Permian formation, and accompanied by plants and mollusca which seemingly confirm this reference.[1]

In view of these foreign discoveries Mr. Newton concludes that the Elgin sandstones may probably represent more than one reptilian horizon, and that we are confronted with the possibility of their being of Permian age.

The difficulty of drawing a boundary-line between the Trias and the Upper Old Red Sandstone of Elgin, which impressed the mind of the late Dr. Gordon, has had to be faced elsewhere in Scotland. In Arran, my colleague Mr. Gunn has shown that the Trias there rests on the Upper Old Red Sandstone, both formations having a similar inclination. Even he, with his ripe experience, has had great difficulty in drawing a boundary between them on the west side of the island ; but when the base-line of the Trias is traced eastwards to Brodick it passes transgressively on to Carboniferous rocks.

Of special importance is the recent discovery in Arran of the fossils of the *Avicula contorta* zone[2] by Mr. Macconochie, of the Geological Survey, to whose skill as a fossil collector Scottish geology owes much. With these occur Lower Liassic fossils, in sediments which are not now found in place in the island. These fossiliferous patches are associated with fragmental volcanic materials filling a great vent, the age of which will be referred to presently. This discovery has fixed the Triassic age of the red sandstones and marls in the south of Arran. The detailed mapping of the island by Mr. Gunn has demonstrated that the Triassic sandstones rest partly on the Old Red Sandstone, partly on the Carboniferous Limestone Series, and partly on the Coal-measures.

In 1878 appeared the third of Professor Judd's great papers on the Secondary Rocks of Scotland, wherein he unravelled the history of these strata as developed in the east of Scotland and in the West Highlands. His admirable researches, in continuation of the work done by Bryce, Tate, and others, embraced the identification of the life-zones, their correlation with those of other regions, the history of the physical conditions which prevailed in Scotland during Mesozoic time, and the working out of the structural relations of the strata.[3] He showed that their preservation on the east of Scotland was due to the existence of great faults, and those in the West Highlands to the copious outpouring of the Tertiary lavas. He was the first to detect the occurrence of Cretaceous rocks in the West Highlands, and to show the marked unconformability which separates them from the Jurassic strata. His main life-zones and his main conclusions regarding the Secondary Rocks of Scotland have so far been confirmed by the detailed mapping of the Geological Survey. An interesting addition to our knowledge of these rocks was made by my colleague Mr. Horace B. Woodward, in the course of his field-work, who

[1] Y. Amalitzky: "Sur les fouilles de 1899 de débris de vertébrés dans les dépôts Permiens de la Russie du nord," Varsovie, 1900.

[2] Summary of Progress Geol. Surv. 1899, p. 133.

[3] Quart. Journ. Geol. Soc., vol. xxix, p. 97 ; vol. xxxiv, p. 660.

found the oolitic iron-ore in the Middle Lias of Raasay, the position of which corresponds approximately with that of the Cleveland ironstone.[1]

The extensive plateau of Tertiary volcanic rocks in the Inner Hebrides has been a favourite field of research ever since the time of Macculloch, the great pioneer in West Highland geology. During the period under review much work has been done in that domain. According to Professor Judd, that region contains the relics of five great extinct volcanoes and several minor cones, indicating three periods of igneous activity. The first was characterized by the discharge of acid lavas and ashes, the molten material consolidating down below as granite; the second by the outburst of basic lavas, now forming the basaltic plateau, connected with deep-seated masses that appear now as gabbro and dolerite; the third by the appearance of sporadic cones, from which issued minor streams of lava.[2]

In 1888 Sir A. Geikie communicated his elaborate monograph on the history of Tertiary volcanic action in Britain to the Royal Society of Edinburgh,[3] which has been incorporated, with fuller details, in his recent work on "The Ancient Volcanoes of Great Britain." His main conclusions may thus be briefly stated: (1) The great basaltic plateaux did not emanate from central volcanoes, but are probably due to fissure eruptions; (2) the basaltic lavas were subsequently pierced by laccolitic masses of gabbro, which produced a certain amount of contact alteration on the previously erupted lavas; (3) the protrusion of masses of granophyre and other acid materials by means of which the basic rocks were disrupted.

During the last six years Mr. Harker has been engaged in mapping the central part of the Isle of Skye and in the petrographical study of the rocks, the results of which have been summarized in the annual reports of the Geological Survey. As regards the basaltic lavas, he finds that while they have been of vast extent the individual flows have been of feeble volume, and show no evident relation to definite centres of eruption. There were two local episodes, however, which took the form of central eruptions: one represented by a number of explosive outbursts at certain points; the other, in the basalt succession, gave rise to rhyolitic rocks.

Mr. Harker further finds that the succeeding plutonic phase of activity, confined in Skye to what is now the central mountain tract, is represented by three groups of plutonic intrusions, in the following order: peridotites, gabbros, and granites. The metamorphism set up in the basaltic lavas near the large plutonic masses presents points of interest, especially the widespread formation of new lime-soda-felspars from the zeolites in the lavas.

After the intrusion of the granite of the Red Hills, Mr. Harker finds that igneous activity took the form of intrusions of smaller volume, but in some cases of wide distribution. The great group of dolerite sills belongs to this period. An enormous number of acid and basic dykes followed, of several distinct epochs. A set of minor basic intrusions of quite late date is found in the gabbro district of the Cuillins, the most interesting of which takes the form of sheets of dolerite, parallel at any given locality, but always dipping towards the centre of the gabbro area. Mr. Harker considers that this remarkable system of injections presents a new problem in the mechanics of igneous intrusion. The latest phase of vulcanicity in the Cuillin district is a radial group of peridotite dykes. As regards the local group of rock in Central Skye Mr. Harker finds that the order of increasing acidity which ruled in the plutonic phase was reversed for the minor intrusions which followed.

In connection with the great development of volcanic activity in the

[1] Geol. Mag., Dec. III, Vol. X (1893), p. 493.
[2] Quart. Journ. Geol. Soc., vol. xxx, p. 220.
[3] Trans. Roy. Soc. Edinb., vol. xxxv, pt. 2, p. 23.

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West of Scotland in Tertiary time reference must be made to the remarkable volcanic vent in Arran, the recognition of which is due to the suggestion of my friend Mr. Peach. This volcanic centre covers an area of about eight square miles, and lies to the south of the granite area of the island.[1] The vent is now filled with volcanic agglomerate and large masses of sedimentary material, some of which have yielded the Rhætic and Lower Lias fossils already referred to, the whole being pierced by acid and basic igneous rocks. One of the interesting features connected with it is the occurrence of fragments of limestone with the agglomerate, which has yielded fossils of the age of the Chalk, thus proving that the vent is post-Cretaceous. There is thus strong evidence for referring the granite mass in the north of the island and most of the intrusive, acid, and basic igneous rocks to the Tertiary period. It furnishes remarkable proof of the Tertiary age of the Arran granite suggested by Sir A. Geikie in 1873.[2] The story unfolded by this discovery is like a geological romance. The former extension of Rhætic and Lower Lias strata and of the Chalk in the basin of the Clyde, and the evidence of extensive denudation in the south of Scotland, appeal vividly to the imagination.

This outline of the researches in the solid geology of Scotland would be incomplete without reference to the publication of Sir A. Geikie's great work on "The Ancient Volcanoes of Great Britain" (1897), in which the history is given of volcanic action in Scotland from the earliest geological periods down to Tertiary time. To investigators it has proved invaluable for reference. Nor can I omit to mention the new edition of his volume on "The Scenery of Scotland," wherein he depicts the evolution of the topography of the country with increasing force and fascination. In this domain it may be said of the author, "Nihil quod tetigit sed ornavit."

II.—Egyptian Geology.—We have much pleasure in noticing "Geological Survey Report, 1899, Part III, Farafra Oasis; its topography and geology, by Hugh J. L. Beadnell," issued in July, 1901, by the Survey Department, Public Works Ministry at Cairo. This, the second report issued, follows closely on Part II, and consists of 39 pp., 4 maps, and many sections. The report is divided into Introduction; Topography, with notes on the Wells, Population, etc.; Geology; the Desert between Farafra and Dakhla; and Geological Summary. The geological summary shows that in the district under notice the lowest rocks met with are correlated with the Danian of Europe. These consist of, from below up, clays and sandstones of Ain el Wadi, with plant remains and silicified wood; hard blue-grey limestones and White Chalk with brachiopods, lamellibranchs, annelids, etc. Above these come shales, occasionally present, with an abundance of fossils, beds probably representing locally the upper part of the White Chalk. The Eocene is represented in its lower part only by limestones of the plateau with numerous echinids, lamellibranchs, and many foraminifera (Libyan series) at the top, while below come the Esna Shales, in part fossiliferous and with *Operculina* limestone occasionally at the base. The recent deposits are seen in the soils and clays of springs with recent fresh-water shells, blown sand, and local and unfossiliferous marls and clays. The report will be of the highest value, and like

[1] Quart. Journ. Geol. Soc., vol. lvii (1901), p. 226.
[2] Trans. Geol. Soc. Edinb., vol. ii, p. 305.

its predecessor is exceedingly well got up; we await the future parts with the greatest interest. One thing we would ask of the Director-General, Captain Lyons, and that is, to allow the word 'Egypt' to appear somewhere on the title-page.

III.—Economic Geology.—Messrs. John C. Branner and John F. Newsom have issued a second edition of their "Syllabus of a course of Lectures on Economic Geology," 1900, in a volume printed on one side of the paper only, of 368 pp. One of the most important things a student of economic geology needs to learn is where to find and how to use information that has been published. The authors have therefore given references, first, to works on the general subject; second, to periodicals in which articles are to be looked for upon various economic subjects; third, to papers and reports on special subjects. Naturally in a book issued by the Professors of the Leland Stanford junior University, more space is given to the economic geology of the United States than to that of other countries. The book has a good index, and is illustrated by a number of charts and sections. The compositions of minerals are mainly taken from Dana.

IV.—Canadian Geology. Sessional Paper No. 26, 64 Victoria, Summary Report of the Geological Survey Department, for the year 1900, is an octavo of 203 pages and forms an important and interesting document. It has, moreover, a melancholy interest in that it is the last report from the pen of the late G. M. Dawson. In this report especial prominence is given to the results of field-work, "thus affording an early publication of a preliminary kind for any new facts obtained," an object that entitles this report to especial attention. During the year 1900 twelve new maps were completed and finished, and eighteen others were either in the engraver's hands or in the press. Mr. James White has completed his Altitudes in the Dominion of Canada, and this will shortly be issued. Attention is again drawn to the inadequate safety of the present Museum and offices. It is a penny-wise-and-pound-foolish policy to allow such precious and costly records to continue exposed to the danger of fire. After a series of reports on economic minerals, a good account is given of the exhibit sent by Canada to the Paris Exhibition, and the report proper opens on p. 37 with a detailed account of the Yukon district. The areas explored are those of the Stewart and Yukon rivers, the coals and lignites of the Klondike river, and the copper deposits of White Horse. From p. 52 work accomplished in British Columbia is detailed, and a map of the Atlin Goldfields is appended, the geology of which is provided by Mr. J. C. Gwillim. Mr. J. M. Bull reviews the explorations carried out in the Mackenzie district, after which the report deals with Canada proper, New Brunswick, and Nova Scotia. As regards zoology, the chief item of interest is the announcement that Professor H. F. Osborn is at work upon the vertebrate remains collected from the Cretaceous rocks of the Red Deer River, and drawings have already been prepared for the report which it is hoped will soon be issued. Lambe's "Revision of the Genera and Species of the Madreporaria Aporosa and Madreporaria Rugosa" has been published, and Whiteaves' fourth part of Mesozoic Fossils was issued in November, 1900.

V.—CANADIAN PALÆOZOIC CORALS.—Lawrence M. Lambe has issued part ii of his Revision of the Genera and Species of Canadian Palæozoic Corals, as Contributions to Canadian Palæontology, vol. iv, pt. 2. This part deals with the Madreporaria Aporosa and the Madreporaria Rugosa, and consists of 200 pages and 13 plates. The work is of considerable value and seems to have been prepared with much care; there is little new in it, but that perhaps shows more exactly the attention which the author has paid to his predecessors. Perhaps Nicholson's work might have been more carefully studied. We do not grasp the author's reasons for rejecting the genus *Heliophyllum* and placing the species under *Cyathophyllum*, or for using *Arachnophyllum* in the place of *Strombodes*. The monograph is a valuable addition to the literature of the Palæozoic Madreporaria, and we hope the author will be encouraged to continue it.

VI.—PALÆOZOIC CRUSTACEA.—In the 54th annual report of the New York State Museum, 1900 (1901), J. M. Clarke has some notes on new Crustacea. One of these, the peculiar, eyeless, semi-trilobitic merostome, called *Pseudoniscus* by Nieszkowski in 1859, has been found in the *Eurypterus* dolomites of Litchfield, Herkimer County, and is described under the name of *P. Roosevelti*. Some of the American specimens are perfect, and Mr. Clarke has been enabled to add a good deal to our knowledge of the animal. The other new Crustacea described in his paper are *Ceratiocaris præcedens*, *Emmelezoe decora*, and *Estheria Ortoni*; the latter is a Coal-measure form and was found at Carrollton.

VII.—NEW GEOLOGICAL MAP OF THE MONT BLANC MASSIF.—Professors Duparc and Mrazec have issued the map to accompany their memoir on Mont Blanc, published in 1898 by the Société Physique et d'Histoire Naturelle de Genève. They had the collaboration of Dr. Pearce for the Val Ferret region and for the Courmayeur synclinal. The map is based on that of Albert Barbey, but includes Mont Catogne; its scale is 1:50,000, and it is clearly printed and lightly tinted in colour. The publisher is Comptoir Minéralogique et Géologique Suisse, Minod, 6, Rue St. Léger, Geneva. Price not quoted. The publishers also announce the completion of collections of rocks referred to in Professors Duparc and Mrazec's memoir, 49 specimens for 180 francs.

VIII.—GEOLOGY OF THE PHILIPPINE ISLANDS.—The United States Geological Survey has included in its twenty-first annual volume a report on the Geology of the Philippine Islands. The work was entrusted to George F. Becker, who has produced an admirable resumé of the work of all who have gone before, and has added to that observations of his own, taken at considerable disadvantage owing to the unsettled state of the Islands. The report is rather an attempt to bring together all that is known than to provide a new and complete account of the geology of the Philippines. Becker lists some 100 papers on the subject, and has provided a translation of Martin's paper on the Tertiary Fossils which was published in 1895. He also gives two excellent maps of the Islands, drawn by the Jesuit Fathers, and has utilized a sketch of the mineral resources compiled for him from the archives of the Inspección de Minas by Luis Espina. Becker accompanied General Otis to Manila, and remained in the Islands fourteen months, but could accomplish little original work because of the attitude of the natives. The paper will be very useful to all subsequent workers, and this seems to be its real purpose.

IX.—New Brachiopoda, etc.—(1) Suppl. zu d. Beschreibung der Silurischen Craniaden der Ostseeländer. Friedrich Hoyningen Huene. K. Russ. Mineralog. Gesellsch. zu St. Petersburg, 1900, Ser. II, Bd. xxxviii, No. 1, with 3 plates. (2) Ueber *Aulacomerella*, ein neues Brachiopodengeschlecht. Idem, with plate. (3) Beiträge zur Beurtheilung der Brachiopoden. F. H. Huene. Centralblatt für Mineralogie, etc., 1901, woodcut. (4) Cambrian Brachiopoda: *Obolella*, subgenus *Glyptias*; *Bicia*; *Obolus*, subgenus *Westonia*; with Descriptions of New Species. C. D. Walcott. Proc. U.S. National Museum, 1901, vol. ii.

The first of these four pamphlets contains figures and descriptions of species belonging to different genera of Silurian Craniadæ, illustrations of the shell-structure of two genera, *Pseudocrania* and *Pseudometopoma*, geographic-geologic tables, and other important matter. In the second contribution two species of a new genus, *Aulacomerella*, are described and figured. The genus is said to show senile characters; and also to be a homœomorph of *Aulacorhynchus*, a fact referable, the author suggests, to "repetition of development." The third paper is a later contribution by the same author. It discusses the bearing of certain facts upon studies of Brachiopods, dealing especially with some important anatomical results of F. Blochmann. The author also calls attention to the great confusion in the nomenclature of the shell muscles, pleading for a uniform Latin system. The last paper is a forerunner of a monograph. A new genus, two new subgenera, and several new species are described; but there are no figures. We much regret to find so eminent a palæontologist as Dr. Walcott countenancing so very undesirable a practice.

REVIEWS.

I.—Fauna der Gaskohle und der Kalksteine der Permformation, Bohems. By Dr. Anton Fritsch. Vols. i–iv: pp. 552, 394 text-figures and 165 chromolithographic plates.

After devoting thirty years of almost continuous work to its study and elucidation, the author, Dr. Anton Fritsch, has completed the illustration and description of the Permian Fauna of Bohemia, the marvellous richness of which has surprised all students of palæontology; and we congratulate our distinguished fellow-worker upon having lived to achieve so important an undertaking.