Chapter 2 Previous literature relating to the geology of the region described in this memoir

By J. Horne.

Towards the close of the eighteenth century brief references were made to the occurrence of certain rock-groups in the North-West Highlands, which have now become widely known in geological literature. In 1774 Pennant<ref>A Tour in Scotland and Voyage to the Hebrides. Vol. ii., pp. 365, 366. </ref> recorded exposures of limestone and marble in Ross-shire and at Ledbeg in Sutherland; and in 1789 Williams<ref>The Natural History of the Mineral Kingdom. Vol. i., 1st ed., p. 472.</ref> mentioned that granular quartz or primitive sandstone is found in parts of Ross-shire and the mountains of the north of Scotland.

The first important contribution to our knowledge was made by Macculloch<ref>A Description of the Western Islands of Scotland, vol. i., pp. 1–234, 295, *et seq.* pp, 89, 104, 508, 515; and vol. iii., with plates and maps. On the Geology of various parts of Scotland, *Trans. Geol. Soc.,* ser. 1, vol.ii pp. 388, 450. A Geological Classification of Rocks, London, p 333 " Supplementary Remarks on Quartz Rocks, *Trans. Geol. Soc.,* ser. 2, vol. i., pp. 53–60.</ref> — the great pioneer in West Highland geology — who, between 1814 and 1824, described a remarkable development of red sandstone, quartz-rock and limestone among the gneiss and schists of the North-West Highlands and Islands. He maintained that the red sandstones and conglomerates (Torridon) rest unconformahly on the western gneiss, and that, in Sutherland, they are overlain by quartz rocks and limestone, which alternate with and are succeeded by gneiss and schists forming the chief portion of the Highlands of Scotland. He announced the important discovery of worm tubes (named by Salter, *Serpulites Maccullochii*) and *Orthoceratites* in the quartz rock of Loch Eireboll, and he noted "the occurrence of certain cylindrical bodies" in the quartzites of Assynt and the Coigach. The limestone of the Garbh Island was regarded by him as a fragment of the limestone basin of Durness. Allusion was made to the "red vermicular stains" in its grey base and to the singular forms on its weathered surface, which, in his opinion, indicated that such remains entered into the composition of the rock. He stated that, along the eastern shore of Loch Eirebol, the superposition of the quartz-rock to the limestone and of the gneiss to the quartzite can be seen at various points; and further that, in Sleat and Loch Alsh, at Glenelg and Loch Carron, the red sandstones (Torridon) graduate upwards into gneiss and schists.

From this brief outline it will be seen that this astute observer established two points of permanent value, viz., the unconformability between the western gneiss and the overlying red sandstones (Torridon) and the occurrence of the zone of Serpulite Grit (*Salterella* quartzite). By correlating the limestone at Garbh Island with that at Durness, he inferentially suggested the system of east and west faults in that region, and while noting the occurrence of an upper quartzite and the superposition of the eastern gneiss and schists to the quartzite and red sandstones, he recorded certain facts, the correct interpretation of which led to prolonged controversy in future years.

In 1827 Murchison and Sedgwick visited north-west Sutherland, and in 1829 they communicated to the Geological Society a paper on "The Structure and Relations of the Deposits contained between the Primary Rocks and the Oolitic Series in the North of Scotland", in which they correlated the red sandstones (Torridon) between Cape Wrath and Durness with the red sandstones of Tongue, and thus with the Old Red Sandstone of Caithness.<ref>*Trans. Geol. Soc.,* ser. 2, vol. iii., p. 125.</ref>

In his "System of Geology" which appeared in 1831, Macculloch distinguished between the primary sandstone in Ross and Sutherland, where it is associated with quartz-rock and the secondary sandstones with fossils in the west of Scotland.<ref>A System of Geology, vol. ii., ch. 29.</ref>

In 1841 Hay Cunningham confirmed Macculloch's observations regarding the unconformability between the red sandstones (Torridon) and the underlying gneiss, and the occurrence of an upper gneiss resting on the quartz-rocks and limestones. He further corroborated the discovery of organic remains in the quartz-rock, and stated that "there are gneisses and mica-slates that have been elaborated after these were called into being.<ref>Geognostic Account of the County of Sutherland, *Trans. High. Soc.,* vol.xiii., p. 73, vol. vii., new series, p. 73.</ref>

In his volume on "The Old Red Sandstone" published in 1841, Hugh Miller correlated the red sandstones in the west of Sutherland and Ross with the red sandstones in the basin of the Moray Firth. He contended that, in Assynt, these strata are succeeded by (1) a lower quartz-rock; (2) massive limestone, and (3) an upper quartz-rock, the last member being exposed in Glas Bheinn and Ben More. He admitted that, in Eireboll, the eastern gneiss does seem to overlie the quartz-rock.<ref>The Old Red Sandstone, 1st *ed.,* ch. ii. (1841). On the Red Sandstone, Marble, and Quartz Deposits of Assynt, published in 16th ed., p. 325. </ref>

In 1894 Nicol referred to the development of the red sandstones resting unconformably on the gneiss in the North-West Highlands, and noted that it is succeeded by quartz-rock and limestone which, at certain localities in Loch Eireboll, pass underneath the Eastern gneiss. He suggested that the primary strata of the Highlands are the metamorphic representatives of the Silurian rocks of the South of Scotland.<ref>Guide to the Geology of Scotland, p. 210, *et seq.*</ref>

A suggestive memoir was published by Mr. Daniel Sharpe in 1852 on the foliation of the rocks of the Northern Highlands, in which he endeavoured to show that foliation is the ultimate stage of cleavage. He distinguished between the gneiss lying east and west of a line drawn from Loch Eireboll to the head of Loch Maree, the foliation and cleavage of the western area and of Lewis striking north-west and south-east, and that of the eastern area north-east and south-west.<ref>On the Arrangement of the Foliation and Cleavage of the Rocks of the North of Scotland, *Phil. Trans.*, vol. cxlii., p. 445.</ref>

The discovery by Charles Peach in 1854 of fossils in the DurnessLimestone aroused keen interest in these rocks and led Sir Roderick Murchison to revisit the North-West Highlands. He invited Professor Nicol to accompany him, and the two observers went over some of the northern sections together in the autumn of 1855. At the British Association meeting of that year he communicated a paper "On the Relations of the Crystalline Rocks of the North Highlands to the Old Red Sandstone of that region, and on the recent discoveries of Fossils in the former by Mr. Charles Peach", which gave the results of observations made during this joint traverse. Murchison contended that all the crystalline rocks of that area (gneiss, schists, clay-slates) were originally stratified deposits that had been crystallised before the beginning of the Old Red Sandstone period. He correlated the quartz-rocks and limestones of Durness with their equivalents at Eireboll, stating that in the latter region they pass under the eastern gneiss and schists. Owing to their imperfect preservation the age of the fossils could not be definitely determined, but Salter provisionally regarded them as belonging to the Devonian genus *Clymenia* or to *Goniatites* and *Euomphalus.* Murchison suggested that they might be of Lower Silurian age, and hence he separated the western gneiss from the eastern schists, which he considered to be younger than the fossiliferous limestones. The red sandstones of Apple-cross, etc., were still supposed by him to be the equivalents of the Old Red Sandstone of the east coast.<ref>Rep. *Brit. Assoc.* for 1855, p.85.</ref>

An important advance was made by Nicol when, towards the close of 1856, he communicated to the Geological Society a paper "On the Red Sandstone and Conglomerate, and the Superposed Quartz-rocks, Limestones and Gneiss of the North-West Coast of Scotland", wherein he described various sections extending from Loch Eireboll to the southern part of Skye, examined partly in 1855 in company with Murchison, and partly in 1856 by himself.<ref>Quart. *Jour. Geol. Soc.,* vol. xiii., p. 17, published in 1857.</ref> One of the prominent features of this paper is the detailed evidence in Support of an unconformability between the red sandstones (Torridon) and the overlying quartzites which he had detected and traced for upwards of 100 miles. The following order of succession is given:

1. The red sandstone is the lower formation resting on gneiss and forming a narrow band along the western shore, never reaching the watershed of the country and not exceeding twenty miles in breadth.
2. The quartzite is a distinct and newer formation reposing unconformably on the red sandstone on the west, but on the east spreading out beyond it over the gneiss. Its present breadth, including outlying portions, does not exceed ten miles, and is generally much less. The limestone forms the upper portion of this band.
3. At many points along the eastern margin the quartzite and limestone have been ascertained to dip under gneiss inclined in the same direction towards the south-east.

Nicol suggested that the quartzite occurring east of the limestone in Assynt is probably only the lower quartzite rising from underneath that zone or brought up by a fault. Allusion is made to the rounded bodies of organic origin in the

quartzite (pipe-rock) to the plant-like impressions in the Fucoid beds, to the conical bodies (*Serpulites*) found by Macculloch, and to the fossils obtained by Mr. C. W. Peach from the limestone. He was convinced that the age of the beds could be satisfactorily determined only by the discovery of better preserved fossils, but he provisionally regarded the red sandstones (Torridon) as Devonian and the quartzites and limestones as Lower Carboniferous. Should the latter prove to be of Silurian age, then the Torridon Sandstone would necessarily belong to a different period from that of the Old Red Sandstone with which it had been identified. In several horizontal sections illustrating this paper, the quartzites and limestones are represented as passing below the eastern gneiss, but Nicol expressed a doubt whether the latter might be a newer metamorphic group or a portion of the lower gneiss forced up by some great convulsion.

The marked unconformability between the red sandstones and quartzites detected by Professor Nicol was observed independently by Sir Henry James and described by him in a letter to Sir Roderick Murchison, dated 26th July, 1856.<ref>Life of Sir R. I. Murchison, by A. Geikie (1875), vol. ii., p. 212.</ref>

The discovery by Mr. Peach of additional fossils from the Durness limestone, which were considered by Salter to have strong affinities with certain Lower Silurian forms of North America, ranging from the Calciferous Sand-rock to the Trenton Limestone, gave a new impetus to Murchison in his investigation of the structure of the North-West Highlands. In 1857 he made a communication to the Geological Section of the British Association at Leeds,<ref>*Rep. Brit. Assoc.* for 1857, pp. 82–84.</ref> where he announced that, in view of the unconformability between the red sandstones and the quartzites and the definite nature of the palaeontological evidence as interpreted by Salter, he regarded these red sandstones as the equivalents of the Cambrian rocks of Wales. A note by Salter on the fossils from the Durness Limestone is appended to this paper, in which he states that "the character of the fossils is so very similar to that of the lower limestones of America, often contained in a single calcareous band, that one is tempted to conclude that the succession in North-West Scotland, where a thick limestone reposes on a quartzite full of fucoidal markings, can be nothing else but the equivalent of the Calcareous Series of Canada, with its underlying Potsdam Sandstone".

In 1858 Murchison and Nicol contributed to the Geological Section of the British Association at Leeds brief statements of their views as to the relations of the rocks in the North-West Highlands. Nicol expressed regret that in one point he was compelled to differ from his friend, that he could not regard the entire gneiss forming the central regions of Ross and Sutherland as of younger date than the red sandstone and quartzite of the West Coast. He described a section from Gairloch to the Moray Firth, and showed that both the red sandstone and quartzite resting on the western gneiss were cut off by igneous rocks from the supposed overlying strata on the east. Similar igneous rocks, occupying the same relative position, had been traced by him at intervals for 100 miles, from Loch Eireboll to Skye, and he therefore concluded that the overlap of the eastern gneiss on quartzite might be caused by a slip or convolution of the strata.<ref>Rep. *Brit. Assoc.* for 1858. Trans. of Secs., p. 96.</ref>

With unflagging energy, Murchison prepared an elaborate memoir in two parts "On the Succession of the Older Rocks in the Northernmost Counties of Scotland, with some Observations on the Orkney and Shetland Islands", which he communicated to the Geological Society in 1858.<ref>Quart. *Journ. Geol. Soc.*, vol. xv., p. 363.</ref> He indicated the characters of the western gneiss as exposed in the low maritime headlands in the west of Sutherland and Ross, where the rocks are variously inclined at high angles and highly contorted, are usually hornblendic, and penetrated by granitic veins. He remarked that it will be for future geologists to observe the extent to which this old rock may appear in the central or eastern portions of the northern counties of Scotland, for, although he had failed to detect it in the region east of a line extending from Eireboll to Loch Assynt, it might well occur in parts of the interior which he had not explored. The great succession of Silurian strata resting unconformably on the Cambrian sandstones and the Fundamental gneiss were grouped by him in the following ascending order:(1) Quartz-rock, (2) limestone, (3) upper quartz-rock, (4) micaceous and chloritic schists passing into a kind of gneiss, with repetitions of quartzose and micaceous flaggy rocks. A description by Salter of the organic remains from the Durness Limestone was given in the same paper, together with figures of some of the fossils, wherein that astute palaeontologist made the following striking statement:"That this truly North American assemblage should be found in the extreme north of Scotland, on the same parallel as the Canadian — that species of *Maclurea* and *Raphistoma,* resembling those of the St. Lawrence basin, and *Orthocerata* bearing large siphuncles like those North America, Scandinavia, and Russia, should occur in Scotland and yet be scarcely known further south, is at least suggestive of a geographical distribution — perhaps even of climatical conditions — not very unlike that of more modern times".

The marked change in the petrographical characters of the eastern or younger gneiss was again enforced by Murchison. With reference to the outlying mass of the eastern schists at Bishop's Castle,<ref>This locality is termed Seanachaisteal on the One-Inch Map 114. </ref> north of the Durness Limestone basin, he noticed the occurrence there of thin-bedded grey micaceous flagstone (siliceous Moine-schist) that occasionally weathers white, like the promontory of the Whiten Head, east of Loch Eireboll, and remarked that the observer cannot fail to recognise the distinction between the hornblendic and micaceous gneiss to the west, and this outlying crystalline flagstone, which, though it contains felspar, quartz, and mica, is not hornblendic, and is void of granite veins. He recorded the development of this same type of quartzose flagstone and dark grey micaceous schists east of Loch Eirebol and Assynt, which on Ben Hope, east of the former sea-loch, are associated with green and grey micaceous schists with garnets that present the external aspect of the Italian "Cipollino". He had no doubt that the Silurian quartzites and limestones are overlain by the younger micaceous flagstones of Inverhope and the Moine east of Loch Eireboll, both having a common dip towards the E.S.E, and that they constitute one great series, the age of which is determined both by the order of superposition and by the fossils contained in one of its lower members.

In the same memoir Murchison next proceeds to consider Nicol's conclusion that intrusions of igneous rock appear at intervals between the quartzite and limestone and the younger gneiss, which the latter geologist believed tobe connected with a general dislocation along the strike. He referred to the Canisp porphyry that pierces the lowest part of the Cambrian sandstone on that mountain, to the hypersthenic rocks that penetrate the limestones of Durness and the quartz-rocks and limestones of Assynt, to the syenite and felspar rocks that reappear above the Silurian limestones at Ledmore and on the banks of Loch Borrolan (Assynt), and to the granite mass of Ben Laoghal rising through the younger gneiss in Sutherland. He maintained that these eruptive masses do not derange the general succession, though they occasion partial folds of the beds near the points of local intrusion.

A geological sketch map of the north of Scotland is appended to this paper, in which the western or Fundamental gneiss is correlated with the Laurentian gneiss of Canada, and the eastern schists, together with the quartzites and limestones, are coloured as of Lower Silurian age.

This elaborate memoir was followed in 1860 by a further contribution from Murchison on "Supplemental Observations on the order of the ancient Stratified Rocks of the North of Scotland and their associated eruptive rocks",<ref>*Quart. Journ. Geol. Soc.,* vol. xvi., p. 215.</ref> which embodied the results of a traverse with Sir A. C. Ramsay in the previous year. Again he points out the divergence in strike between the Laurentian gneiss and the eastern schists, that of the former being N.N.W. and S.S.E., and that of the latter, approximately, N.N.E. and S.S.W. He advances fresh evidence in support of his contention that the Silurian limestones are intercalated between a lower and an upper quartzite, and that at certain localities there is an upper limestone between the upper quartzite and the eastern schists. On the authority of Professor Harkness, he gives a section showing the upper limestone at Cnoc an Droighin (Inchnadamff), and another showing the upper quartzite and limestone pierced by intrusive rocks on the west face of Ben Arnaboll<ref>Ben Arnaboll is named Beinn Poll Ath-roinn on Sheet 114 of the One inch map.</ref> (Loch Eireboll). He notes the occurrence of intrusive igneous rocks at various localities near the junction of the quartzite and limestone with the upper gneiss, and contends that they do not affect the order of succession.

In December, 1860, Professor Nicol laid a full and what might be termed a final statement of his views before the Geological Society in a paper, "On the Structure of the North-Western Highlands and the Relations of the Gneiss, Red Sandstone, and Quartzite of Sutherland and Ross-shire". This remarkable contribution embodied the results of his researches extending over several years in the North-West Highlands, and in view of the rare power which it reveals in dealing with complicated tectonics it ought to be studied by all those who are interested in this controversy.<ref>Quart. Journ. Geol. Soc., vol. xvii., p. 85.</ref>

In regard to the relation of the quartzite to the eastern gneiss, discussed in his previous communication to the society in 1856, Nicol stated that "though some of the sections appeared to confirm Macculloch's view that there are in Sutherland two formations of gneiss — an older below the quartzite and a newer superior to it — still the presence of intrusive rocks and other marks of disturbance in the sections he had examined rendered this conclusion less certain and satisfactory than might be wished". In order to determine this question he had subsequently visited this region four times and examined all the principal sections and almost the entire tract from the North Coast of Scotland to Skye in the south, and

from Caithness in the east to the island of Lewis in the west.

The object of this paper is to prove (1) that the limestone is the highest member of the older formations in this region, (2) that no conformable upward succession from the fossiliferous limestone the overlying schists is to be found, "but that the line of junction, where this conformable succession is said to occur, is clearly a line of fault, everywhere indicated by proofs of fracture, contortion of the t$_{i}$rata and powerful igneous action". By means of horizontal sections illustrating the structure of the Eireboll and Assynt regions he shows that the so-called upper quartzite and upper limestone of Murchison's sections are merely repetitions of the lower quartzite and limestone due to faults or folds. He adopted the following order of succession, which is given below in descending order:

4. Limestone
3. Quartzite (Serpulite Grit)
2. Fucoid Beds
1. Quartzite including the pipe-rock with annelid tubes
Unconformity
Red Sandstone (Torridon)
Unconformity
Gneiss and Crystalline Schists

In the Durness area, Nicol correlated the white mica-slates of Farrid (Fair aird on Sheet 114) Head and Old Castle Point (Seanachaisteal) with similar rocks east of the quartzite at Eireboll and at Melness (Tongue). The brecciated character of the limestone in Sango Bay is supposed to be due to a mass of hornblende-rock or serpentine that rises up in that bay, bringing with it portions of altered quartzite and mica-slate. These igneous and metamorphic rocks extending from Sango Bay south to Loch Cealladail have been evidently forced up through the limestone. The quartzite resting on the limestone in Sango Bay has been broken up into an incoherent breccia by a fault and crush; indeed, the basin is traversed by faults trending N.N.E. and S.S.W., and the strata have been tilted up on the west.

Eastwards in the Eireboll region, Nicol showed that between Camas-an-duin and Eireboll House the limestones form a synclinal fold, and that the underlying Fucoid Beds and pipe-rock appear in regular descending order in the hill-slope to the east. He contended that though the Fucoid Beds and quartzites appear to rest on the limestone with an easterly dip this structure is due to an upheaval and inversion of the strata. In the horizontal section of Camas-an-duin (*ibid.* Vol. XVII., p. 88) the igneous rock (granulite) is represented as appearing on the ridge of high ground to the east, bounded on the west by quartzite, capped in part by quartzite and succeeded eastwards by mica slate. Nicol argued that as fragments of mica-slate are found in this mass of granulite, they prove that the mica-slate is the lower and older rock, and therefore cannot normally overlie the quartzite. Similar eruptive rocks occur on Ben Arnaboll, on the hills north-east of Hope Ferry,at Whitten Head (Cean Geal Mor), and Creag na Faoilinn. The granulite on Ben Arnaboll has clearly broken through the strata, resting in one place on the Fucoid Beds, in another on the quartzite, and further east towards Loch Hope is overlain by quartzose beds.

Again in his horizontal section of Assynt (*ibid.* Vol. XVII., P.) Nicol arranged the series of formations in a great syncline, its centre being occupied by the broad mass of limestone at Inchnadamff, while on the eastern limb the quartzite rises from underneath the limestone on the mountains of Ben More and Braebag. The eastern limit of the section shows what he believed be the structure of Ben More as exposed in the wild corries round Dhu Loch More. Granitic gneiss and mica-slate, with intrusive igneous rocks, form the nucleus of that mountain, throwing off the quartzite all around as from a great centre of elevation. He there noted also red sandstone resting on gneiss or mica-slate as shown in his section), regarding which he says (*ibid.,* p. 99) that "there can be no doubt that this is the true western red sandstone (Cambrian of Murchison) brought up in the centre of the so-called upper quartz-rock, and that the synclinal is thus complete in all the formations from the upper limestone to the lowest gneiss". He further stated that "the only obscurity in he sections arises from the synclinal fold in the limestone being conjoined with a great fault in the quartzite, which is thus brought up in enormous crushed masses, so broken that the lines of stratification can hardly be detected; this is especially seen near the foot of Coniveal" (Coinne-mheall) (*ibid.,* p. 97).

Regarding the Loch Ailsh section, Nicol maintained that the upper quartz rock (Murchison) is the continuation of the quartzite of Braebag and Canisp, and that the upper limestone is merely the repetition, in a denuded form on the eastern side of the anticline, of the limestone of Stronechrubie and Assynt.

Various sections in Ross-shire are described by Nicol in support of his views of the relations of the rocks. He refers particularly to one across the mountains east of Loch Torridon (*ibid.*, Figure 13, p . 104), where five isolated patches of quartzite rest on the red sandstone (Torridon) in one continuous ridge, and maintains that, in this instance, "the quartzite is mere fragments of the upper formation brought down repeatedly by faults, and in some cases even forced in below the inferior red sandstone by enormous lateral pressure".

From the evidence adduced Nicol drew the following conclusions:

1. The mode of distribution of the rocks is altogether inconsistent with the hypothesis that the eastern gneiss conformably overlies the red sandstone or quartzite.
2. The diversity of strata brought into contact with the eastern gneiss proves that the line of junction is along a fault and not one of conformable upward succession.
3. That there is here a line of fault and not of conformable overlap is proved by the nature of the formations. Though along the line of fault, and especially where the disturbance has been most violent, the quartzite is often much hardened and semi-fused, still its fragmentary and granular character is quite recognisable. on the other hand, the eastern gneiss and mica-slate said to rest on it are no less distinctly crystalline. He therefore inferred that he sections in the North West Highlands are but the counterpart of those in the Alps, where crystalline rocks are seen resting on unaltered strata, due to the enormous inversion and overthrow, and that a comparatively small amount of inversion and extrusion of older crystalline masses will suffice to explain any of the Scottish sections.

Regarding the strike of the crystalline rocks, Nicol admitted that, in the western region, the general trend is north-west and in the central areas north-east, but this distinction is not universal. He suggested that the gneiss of Scotland may belong to distinct geological periods. With reference to the divergence in mineralogical character between the western and eastern gneiss, he conceded that hornblendic varieties of gneiss are very characteristic of this formation in the west of Sutherland, but the more usual kinds also occur, while in the eastern districts he contended that rocks quite as hornblendic and as thoroughly granitic in character are to be found. In his opinion, the pecular character of the rock has no relation to its age or locality, but to its proximity to the great foci of igneous action. Near the granitic and syenitic eruptions the gneiss appears in the more coarsely crystalline and hornblendic forms.

In the summer of 1860 Murchison revisited the Highlands once again, accompanied by Sir A. Geikie, with the view of tracing the development of the Sutherlandshire series south-westwards through Ross-shire to Skye, and of discovering whether the order observable in Sutherland extended across the mountainous tracts to the south of the Caledonian Canal. For this purpose the authors examined certain sections in the islands of Lewis, Skye, Islay and Jura, likewise in West Ross-shire and south-eastwards to the Highland border. The results of their observations were communicated to the Geological Society in an elaborate memoir in Feb. 1881.<ref>On the Altered Rocks of the Western Islands of Scotland and the North-Western and Central Highlands, *Quart. Journ. Geol. Soc.,* vol. xvii., p.171.</ref>

In the description of the Laurentian gneiss of Lewis, Harris, West Ross-shire, and other localities, Murchison stated that the prevalent strike of the gneiss in those regions is north-west and south-east, and that lithologically it resembled the western gneiss of Sutherland. Once more he emphasised the contrast between the micaceous and hornblendic gneiss underlying the Cambrian Sandstone (Torridon) and the flaggy, quartzose and micaceous strata overlying the limestones and quartzites with a northeast and south-west strike. He declared that "no geologist can confound the Laurentian or Fundamental Gneiss with the so-called gneiss of the superior crystalline schists, which instead of being a massive hornblendic and granitoid rock like the first formed is, on the whole, a flag-like micaceous and quartzose deposit of very different characters". (*Ibid.,* p. 175)

The distinctive feature of this paper is the description of the relations of the rocks in the tract extending from the southern limits of the county of Sutherland across Ross-shire into Skye. One section in particular — Creag a' Knockan — deserves special notice, as it seemed to furnish evidence of an ascending sequence from the undisturbed Silurian strata (quartzite,

Fucoid Beds, limestone) to the overlying quartzose schists without the intercalation of any igneous material (*ibid.,* Vol. XVII., Fig. 2, p. 180), and without the synclinal folding of the beds as shown in Nicol's section of the same cliff (*ibid.,* Vol. XVII., Fig. 10, p. 101). Similar evidence is adduced along the line southwards towards Ullapool. Beyond Loch Broom the authors refer to an interesting section at Loch-an-Nid (*ibid.,* Fig. 7, p. 188), where on the east slope of Sgurr Ban there are two small dark peaks — outliers of a green serpentinous and actinolitic gneissose rock — which are distinctly superposed on the inclined bedding-planes of quartz-rock. Still further north, the development of the rock in Glen Bruachaig, near Kinlochewe is referred to, which seems to invade the quartz-rock, the limestone, and the upper flaggy series, but though it occupies a considerable area the authors contend that it does not interfere with the ascending sequence. The remarkable section on Beinn Liath Mhor, also figured by Nicol (*ibid.,* Vol. XVII., Fig. 13, p. 104), is described (*ibid.,* Fig. 13, p. 196), which shows several intercalations of quartzites in the Cambrian sandstones, their relations being accounted for partly by faults. But in this case and in others where faults or igneous rocks may intervene, the authors maintain that they do not affect the conformable sequence.

From the Silurian base line south-eastwards by the Great Glen and the Black Mount to Loch Tay and Dunkeld, the general relations of the strata are traced with the result that the younger gneiss is believed to have a wide distribution in the central and eastern Highlands, while the quartzites and limestones are supposed to emerge south-east of the Great Glen in the counties of Aberdeen, Perth, and Argyll.

In the course of these traverses the authors made certain observations on the relation between stratification and foliation in the crystalline schists, which were published as a sequel to the memoir just referred to.<ref>On the Coincidence between Stratification and Foliation in the Crystalline Rocks of the Scottish Highlands, *ibid.,* vol. xvii., p. 232.</ref> They adhered to the views of Hutton that the crystalline rocks of the Highlands were originally sedimentary deposits, their crystalline structure being developed after their deposition. Dissenting from the views of Mr. Sharpe, they maintained that the foliation of the schists concides with the original bedding planes, being "nothing more than such an alteration of the original deposits as caused the siliceous, felspathic and micaceous ingredients to form separate layers". (*ibid.,* p. 240.)

At this stage in the review of this controversy it is desirable to state clearly that thedetailed mapping of the region between the north coast of Sutherland and Skye has completely confirmed Nicol's conclusions — (1) that the limestone is the highest member of the Durness series; (2) tliat the so-called Upper Quartzite and Upper Limestone of Murchison's sections are merely the repetition of the lower quartzite and limestone due to folds or faults; (3) that there is no conformable sequence from the quartzites and lime-;tones into the overlying schists; (4) that the line of junction is a me of fault indicated by proofs of fracture and contortion of the strata. In the course of his investigations Nicol's views underwent a process of evolution, and in the form in which he finally presented them he did not grasp certain points which have been established by later observers. We now know that he was in error when he regarded portions of the Archaean gneiss, occurring in the displaced masses, as igneous rocks intruded during the earth-movements, and when he thought the eastern gneisses and schists were merely the old western gneiss brought up to the surface again by great faults. He failed to realise the evidence bearing on dynamic metamorphism resulting from the gigantic disturbances to which the region had been subjected. But notwithstanding these points, he displayed the qualities of *a* great stratigraphist in grappling with the tectonics of one of the most complicated districts in Europe.

On the other hand, the detailed mapping has proved the accuracy of Murchison's contention that the quartzose and micaceous flagstones and garnetiferous mica-schists which overlie the quartzites and limestones with *a* general agreement in dip and strike, are so strikingly different lithologically from the western gneisses that they cannot be merely that ancient rock brought to light by faults. The petrographical study of these rocks has shown that, while the larger part of the old gneiss now exposed in the west of Sutherland and Ross has affinities with plutonic igneous products, the eastern gneisses and schists represent in the main a succession of altered sediments (the Moine Series of the Geological Survey, Caledonian Series of Dr. Callaway) save in certain areas where gneisses of Lewisian types come to the surface. Special reference will be made in Part 5. to these altered sediments, the age of which has not yet been satisfactorily determined.

Before considering the work of later observers, allusion must be made to the fact that both Murchison and Nicol clearly recognised the intrusive character of the great series of post-Cambrian igneous rocks which are so largely developed in Assynt, In 1859 Murchison noted the band of syenitic greenstone<ref>Quart. *Jour. Geol. Soc.,* vol. xvi., p. 221. </ref>

intercalated in the limestone about a mile west from Inchnadamff and the contact alteration produced by it in the overlying rock which has been converted in parts into a crystalline marble; he also recorded the great development of syenite between Ledbeg and the Oykel Bridge.<ref>*Ibid.,* p. 232.</ref>

In 1860 Nicol announced that, in the course of the previous year, he had observed that the Canisp porphyry not only breaks through the quartzite overlying the Torridon Sandstone, but forms a mass more than *a mile* in diameter in the quartzite within a few hundred yards of the Inchnadamff Hotel. From these facts he inferred that the igneous intrusions must have been later than either the red sandstone (Torridon) or quartzite.<ref>*Ibid.,* vol. xvii,p. 99.</ref>

The order of succession advocated by Murchison and supported by Ramsay, Harkness, A. Geikie, and others, seemed to furnish a simple solution of the geological phenomena of the North-West Highlands, and hence met with general acceptance.

In 1878 the controversy was re-opened by Dr. Hicks in a paper "On the Metamorphic and Overlying Rocks in the neighbourhood of Loch Maree".<ref>*Quart. Jour. Geol. Soc.,* vol. xxxiv., p. 811. On the pre-Cambrian Rocks of West and Central Ross-shire, with Petrological Notes by T. Davies, Geol. Mag*.,* decade 2, vol. vii., pp. 103, 155, 222, 266. On some Recent Researches among the pre-Cambrian Rocks of the British Isles, *Proc. Geol. Assoc* ., vol. vii., p. 59. On the Metamorphic and Overlying Rocks in parts of Ross- and Inverness-shires, *Quart. Jour. Geol. Soc.,* vol. xxxix., p. 141.</ref> While agreeing with Murchison that there is a perfect passage from the quartzites, Fucoid Beds, and limestones into the overlying flaggy strata of Glen Logan (Glen Bruachaig on one-inch Sheet 92) and Glen Docherty (Eastern schists) resembling the Lower Silurian flags of Wales, he maintained that these flaggy rocks rest unconformably on the pre-Cambrian Archaean rocks of Ben Fyn to the east (Fionn Bheinn, Sheet 92). He also regarded the mass of syenite and granitoid rock in Glen Logan ("Logan Rock" of Heddle) as intrusive and of later date than the Silurian strata. Subsequently Dr. Hicks disputed that the eastern schists rest conformably on the quartzites and limestones, and he abandoned the view that the igneous rock in Glen Cruchalie (Glen Bruachaig on Sheet 92) is intrusive in the latter. He arranged the pre-Cambrian rocks in three groups — (a) lower, consisting of massive gneisses (Loch Maree); (b) middle, comprising more banded gneisses (Loch. Shiel); (c) upper, composed of crystalline schists (Ben Fyn); and contended that between Glen Shiel and the eastern border of the Highlands there are representatives of various Archaean rocks with patches of Silurian strata resting on them unconformably.

The mammillated contour so characteristic of the plateau of Lewisian gneiss was attributed by Sir A. Geikie in 1880<ref>Nature, vol. xxii., p. 400.'</ref> to the action of land-ice, and he compared the overlying breccia of Torridon Sandstone age that fills up the hollows and buries the rounded domes of rock near Gairloch to moraine stuff.

In 1880 the first important advance towards the solution of the problem of the succession in the North-West Highlands since the publication of Nicol's researches was made by Professor Bonney, who described the so-called "intrusive syenite" of Glen Logan (Glen Bruachaig on sheet 92), pointing out the occurrence of foliation in the rock, the north-west strike, from which he inferred that all the so-called syenite, save some dykes, is simply a rather granitoid variety of the Hebridean gneiss. He showed that its junction with the limestone, Fucoid Beds, and quartzites is a faulted one, and indicated the direction of the fault. He called attention to a marked fragmental structure in a green schist occurring in the mass, which he attributed to crushing *in situ*<ref>Petrological Notes on the Vicinity of the Upper Part of Loch Maree*", Quart. Jour. Geol. Soc.,* vol. xxxvi p. 93</ref>He disputed the statement of Dr. Hicks about the unaltered character of the newer series in Glen Logan and pointed out that they are rightly classed with the metamorphic rocks as they consist of dark green schists, dull coloured mica-schists and micaceous quartzites.

In 1881 Professor Heddle published a Geological Map of Sutherland, in which he separated the Hebridean or western gneiss from the upper or eastern gneiss, and regarded the limestone of Durness as Silurian and the dolomite between Loch Eireboll and Stromeferry as Archaean. The important feature of this map lay in the detailed representation of the various isolated areas of "Logan Rock", which are now known to be thrust masses of Lewisian gneiss, displaced by post-Cambrian movements, between Loch More and the southern limits of the county. In a series of papers by the same author which appeared in the *Mineralogical Magazine*,<ref>On the Geognosy and Mineralogy of Scotland, *Mineralog. Mag.,* vol. iv., pp. 135, 197; vol. v., pp. 71, 133, 216, 271</ref>based on observations made by him during extensive traverses throughout the county, the evidence for this classification was given. He maintained that the eastern schists

and gneiss rest conformably on the quartzo-calcareous series which extends from Loch Eireboll to Loch Kishorn, the whole being regarded *as* Archaean, because the calcareous rocks at Durness had not been proved to be the same as those at Loch Eireboll. He contended that chemical analysis showed the calcareous strata at Durness to be limestones and those at Loch Eireboll to be dolomites. He regarded the limestones and quartzites of the Durness basin as a fragment of Silurian strata let down by faults intersecting at three points and having no relation with the quartzo-calcareous series of Eireboll. He applied the term "Logan Rock" (from Glen Logan near Kinlochewe–Glen Bruachaig on Sheet 92) to the thrust masses of Lewisian gneiss, and indicated certain petrological differences between this rock and the western gneiss. Following the classification of Cunningham, he grouped the "Logan Rock" with the Upper Gneiss and defined it as "a grit which presents varying degrees of metamorphism up to a perfect gneissic structure". He further gave a large list- of minerals from the crystalline schists and gneisses throughout the county, and described various types of the post-Cambrian intrusive rocks that are so abundant in Assynt.

In 1880 Dr. Callaway visited Durness and Inchnadamff, the results of his observations being communicated to the Geological Society in the following year.<ref>*Quart. Jour. Geol. Soc.,* vol. xxxvii., p. 239.</ref> Regarding the Durness sections, he indicated the existence of an east and west fault separating the gneiss and schists of Farrid Head (Fair-aird on Sheet 114) and Bishop's Castle on the north from the Durine limestone on the south, and claimed that hence there can be no conformable sequence between the two at that point. He noted the occurrence of chloritic and hornblendic gneiss underlain by dark mica-schist in Sango Bay, which he believed to be faulted against the limestone on both sides. The author correlated the Sango Bay gneiss with that which underlies the flaggy schists on Farrid Head and east of Loch Eireboll, and separated it from the Lewisian or Hebridean gneiss. According to Murchison's view the Sango Bay gneiss and schist overlie the limestone, but Dr. Callaway considered that it is "more reasonable to infer that the limestone was deposited on the contorted gneiss, and that the latter was subsequently thrust up through the former between two parallel faults" (*ibid.,* p. 242).

In 1881 Professor Hull stated in reply to objections advanced by Dr. Callaway that he concurred with Murchison's interpretation of the succession north of the Caledonian Canal. From an examination of the sections near Ullapool, at Inchnadamff, in the Forest of Arkle, and the hills bordering Loch Stack, he considered the geological sequence to be remarkably clear, and thus proving a regular passage from the quartzites and limestones to the eastern schists.<ref>The Geological Age of the North Highlands of Scotland", *Nature,* vol. xxiii., p 289.</ref>

Similar views to those of Professor Bonney regarding the "Logan Rock" were advanced by Mr. Hudlestone in 1882, who described it as the local representative in the Ben More Assynt range of the Fundamental Gneiss, and "as the frame work or core round which the newer rocks are folded". He disputed the existence of the " upper quartzite", but considered that the section at Creag-a'-Knockan shows a regular ascending series from the Silurian rocks to the upper gneiss.<ref>Impressions of Assynt, *Geol. Mag.,* decade 2, vol. ix., p. 390.</ref>

The investigations of Dr. Callaway relating to the districts of Loch Broom, Assynt, and Loch Eireboll still further weakened the belief in Murchison's order of succession. A detailed account of his researches was communicated to the Geological Society in 1883, and published in that year.<ref>The Age of the Newer Gneissic Rocks of the Northern Highlands, Quart. *Jour. Geol. Soc.,* vol. xxxix., p. 355.</ref> His view of the relation between the Durness Limestone and the eastern gneiss differed to some extent from all those previously advanced, though it approximated most nearly to that of Nicol. He maintained with that author that the junction of the limestone with the eastern gneiss is a line of faulting and inversion; at the same time he recognised the lithological distinctions between the western and eastern gneisses, and grouped them in two great formations of pre-Cambrian age — (a) the Hebridean, (b) the Caledonian — the latter resting unconformably on the former. He maintained that Nicol's "igneous rock" (granulite), which overlies the limestone in certain localities, is usually a true gneiss, and that both the older and younger gneissic systems have been brought up over the limestone by overfolding and faulting without materially altering their original structures.

While admitting the chemical distinction between the limestone of Durness and the dolomite of Eireboll (*ibid.,* p. 363), referred to by Dr. Thomas Anderson and Professor Heddle, Dr. Callaway regarded the quartzo-calcareous rocks of the two areas as of the same age. Under the term Assynt Series he included the following sub-divisions — C_1, Torridon Sandstone and Ben More Grit; C_2, the Quartzite, comprising a lower seamy subgroup and an upper Annelidian or pipe-rock zone; C_3, Fucoid Beds; C_4, Salterella Grit and Quartzite; C_5 Dolomite. He described in detail various sections in

the districts of Ullapool, Assynt, and Loch Eireboll, and gave the following summary of his results:

1. The Assynt Series has been doubled back on itself in a compressed synclinal fold along Loch Eireboll, so that the quartzite is brought up on the dolomite. In Assynt, also, the quartzo-dolomitic group has been folded back, though less conspicuously. On Loch Broom the dolomite does not come into contact with the Eastern Gneiss, but is separated from it by older faulted rocks.
2. The Assynt Series and the Eastern Gneiss, in the three areas described, display a discordant strike and dip. On Loch Broom the dip of the former is north-easterly, that of the latter southeasterly. In Assynt, where the rocks are in contact, as at Glen Coul, the dip of the gneiss is north-easterly, that of the quartzite south-easterly. On Loch Eireboll there is a double discordance, both the gneiss and quartzite, taking them from north to south, coming respectively into contact with higher and higher beds of the other group.
3. The "Igneous Rock" of some authors, "Logan Rock" of Dr. Heddle, is usually the Hebridean gneiss. On Loch Broom it is brought into contact with almost every member of the Assynt Series in turn, and slightly overlies them. In Assynt this gneiss, sometimes accompanied by the Torridon Sandstone, is thrown over on to the Assynt Series, the overthrow increasing in breadth northwards, so that on Loch Glen Caul it is more than a mile wide. The "intrusive granulite" of Nicol is the Arnaboll gneiss overlying the quartzite and associated rock.
4. The patches of quartzite resting on the "granulite" east of Loch Eireboll are really outliers of the Assynt Series resting unconformably on the Arnaboll gneiss. The absence of granite veins in the Assynt Series supports this conclusion.
5. The "Upper Quartzite" of Murchison's sequence is, in Assynt, the quartzite below the dolomite repeated east of the fault that brings up the Hebridean gneiss. On Loch Eireboll it is the same quartzite repeated on the eastern side of the great synclinal fold.
6. The "Upper Limestone" is, on Loch Ailsh, marble and crystalline dolomite intercalated in the Caledonian series. Near the Stack of Glen Coul it is the Assynt dolomite repeated east of the fault that brings up the Hebridean gneiss. Above Eireboll House it is a faulted fragment of the dolomite appearing east of the inverted quartzite.
7. The Eastern Gneiss, though actually overlying the Assynt Series in some localities, has been brought into this abnormal position by earth-movements subsequent to the deposition of the latter, and is of greater antiquity.
8. The Eastern Gneiss is widely separated in age from the Hebridean rocks.

In the Appendix to Dr. Callaway's paper (*ibid.,* Vol. XXXIX, p. 416.), Professor Bonney describes the microscopic characters of some of the thrust Hebridean gneisses in Assynt and at Ullapool which show indications of crushing and recementation. In some instances these features have so obscured the original structures that it is difficult to determine the true characters of the rocks.

Subsequently Dr. Callaway referred to certain localities where the members of the Assynt Series become more highly altered towards the junction with the Archwan Gneiss, when the latter by folding or thrust has been made to overlie the former. He maintained that there, is no material alteration in that series underlying the Hebridean gneiss in Glen Coul, because there is no evidence of extraordinary pressure; but near the base of the Stack of Glen Coul, at the junction with the eastern gneiss (Caledonian), the quartzite looses all traces of clastic structure and passes into quartz-schist. He accounts for this progressive alteration by enormous pressure due to the quartzite being "reflexed again and again in closely adpressed folds".<ref>Notes on Progressive Metamorphism", *Geol Meg.,* decade 3, vol. i., No. 5, p. 218.</ref>

In 1884 Professor Bonney communicated to the British Association meeting at Montreal a report On the Archaean Rocks of Great Britain",<ref>*Rep. Brit. Assoc.* for 1884, Reports, p. 529.</ref> in which special reference was made to the relations of the rock-groups in the North-West Highlands. He described the lithological and microscopic characters of the eastern gneiss in Glen Logan, and inferred that it is much more modern than the typical Hebridean rocks, and may possibly have been formed of their debris. He considered that the central Highlands consist of schists and gneisses, with some infolded masses of grit, quartzite, schistose and slaty beds, probably Palmozoic, and that the most recent classification of the crystalline rocks in the North-West Highlands would be as follows: (a) coarse gneisses, Loch Maree series; (b) more variable bedded gneisses, Loch Shiel series; (e) mica-schists, quartz-schists and friable gneisses, Gairloch and Ben Fyn; (d) flaggy schists, Glen Docherty. He believed that after the deposition of the Palaeozoic rocks of the north-west, an epoch of mountain-making ensued, the direction of pressure being north-west to south-east, which caused newer beds to be folded together and inversions or faults on a gigantic scale.

Selecting the region of Durness and Eireboll, Professor Lapworth mapped a large portion of it in great detail during the summers of 1882 and 1883. In the pages of the *Geological Magazine*<ref>Geol. Mag., new series, decade 2, vol. x., pp. 120, 193, 337.</ref> he Published a series of papers on " The Secret of the Highlands", in which he described the geological structure of that region, con-n_ rm. mg Nicoll's conclusions (1) that the Durness Limestone is the highest member of the Ordovician series (Lower Silurian, Murchison), (2) that the "Upper Quartzite" and "Upper Limestone" are non-existent, (3) that there is no conformable sequence from the quartzites and limestones into the eastern gneissic series, (4) that the line of junction of the unaltered Palsaozoic rocks is a line of fault and overthrust.

This author believed that the Highlands of Scotland include a portion of an old mountain system, formed of a complex of rock-formations of very different geological ages, which have been crushed and crumpled together by excessive lateral pressure, locally inverted, profoundly dislocated, and partially metamorphosed. In the area partly worked out by himself he recognised the stratigraphical phenomena to be identical in character with those developed by Rogers, Suess, Heim and Brögger in extra-British mountain regions.

In the Durness area he pointed out that the basal quartzite rests on the almost vertical edges of the Lewisian gneiss, followed by the pipe-rock. Next in order comes the limestone, which, though at first sight apparently of great thickness, is made up of a few distinct lithological zones, repeated by faults or inverted folds. From specimens collected by himself, and analysed by Dr. Tilden, F.R.S., he proved that many of the beds in the Durness basin are dolomites, and thus disposed of the classification advanced by Professor Heddle (see page 24). He further showed that the limestone' is visibly overlain in clear sections and at a low angle by a series of wrinkled shales, micaceous flagstones and slaty schists, with intercalated zones of hornblendic gneissose schists; and even where transversely faulted against the limestone, this overlying series agrees precisely in dip, strike, and apparent amount of convolution. He pointed out that, as this physically overlying series is the upper flaggy gneiss of Murchison, it would appear at first sight that Murchison's theory of the sequence, so far as the Durness area is concerned, is absolutely impregnable.

Passing east to Loch Eireboll, Prof. Lapworth described the development of the zones overlying the pipe-rock (Fucoid Beds, Salterella Grit, limestone) on the headland of An-t-Sron and in the neighbourhood of Camas Bay, on the east side of that loch. He showed that the limestone is arranged in a syncline that stretches south to Eireboll House. Eastwards the basin is abruptly bent upwards, and the underlying strata emerge in descending order on the hill slope south-east of the A n-t-Sron till we reach the thin conglomerate at the base of the quartzite that rests unconformably on the " igneous rock" (Sutherland gneiss). On the platform above the ridge there is a narrow island or outlier of quartzite surrounded by this crystalline rock or gneiss, and separated from it by a similar thin basal conglomerate, thus affording clear evidence of a distinct unconformability between the two series. The author discusses the principles of mountain structure, the development of overfolds and overfaults, the deformation of individual strata, and the deformation of mountain folds under the influence of horizontal thrust or earth-creep.

Subsequently, the results of his work, in so far as they affect the age, composition, and mode of formation of the eastern schists, were read by Professor Lapworth at a meeting of the Geologists' Association, July 4, 1884, and published in the following year,<ref>*Proc. Geol.* Assoc.,˜vol. viii., p. 438; *also Geol. Mag.,* new series, decade 3, vol. ii., p. 97 (1885).</ref> the main points of which are here summarised.

In the district round Eireboll and Durness, the so-called Eastern (or Upper) Gneiss is composed of two distinct members. The older is the Arnaboll Gneiss, which is, in his opinion, the so-called Laurentian, brought up to the east of the Assynt (Durness–Eireboll) series by gigantic overfolds. The younger member is composed of the schistose metamorphic rocks of the Moine and Central Sutherland, and contains within it strips and patches of the lower zones of the Assynt (Durness–Eireboll) series. The schistose quartzites or quartz-schists of some authors are the crushed and mechanically metamorphosed ends of long wedges of the Assynt Series, and are often in visible continuity with the unaltered Assynt beds. The intermixture of Archaean and Assynt rocks is so complete that they can never be separated in the field, but must be mapped simply as metamorphic.

The planes of foliation and schistosity in the so-called Upper Metamorphic Series of Sutherland are not planes of bedding; but plains of cleavage or gliding planes, along which the rocks have yielded to the irresistible pressure of the lateral earth-creep during the process of mountain-making. Granites, syenites, pegmatites, gneisses, and quartzites have

been crushed to powder, and have been finally flattened out into rocks, having all the external characters of halleflintas and even finely laminated shales.

The process of rock-folding in the region is exceedingly complex. Folding, interfolding, buckling, shearing, stretching have all taken place again and again along the junction-plane between the sedimentary strata and the Archaean Series; and innumerable protrusions of igneous material have forced their way in numberless veins in the latter up to the former.

Schists composed of Archwan, Ordovician (sedimentary), and intrusive rocks respectively, form part of one and the same lowest (or heterogeneous) zone in the Eastern schistose area; but further east all recognisable distinctions vanish one by one, and in the present state of our knowledge all that we can presume to say is, that the schists of Central Sutherland are in all probability an intimate compound of sheets of (1) Archaean, (2) Sedimentary, and (3) Intrusive rocks, which have been crushed into slaty rock, wherein crystallisation has been set up along the cleavage planes.

In the Durness–Eireboll region there seems to be no trace of any sedimentary rock of more recent date than the Durness Limestone. The thin, so-called Upper Quartzite band of Sango Bay is the crushed basement zone of the Lower Quartzite. The green schists overlying it are pressure schists, formed and brought over in the great over-fault. The same zone occurs again in Eireboll along the great fault line of the Upper Schist Series.

The great area of metamorphic schists of Sutherland and the Central Highlands is, as a whole, neither Archaean nor Ordovician. The Sutherland (Arnaboll) gneiss is Archaean, but the Sutherland schist has been manufactured since Silurian times. One point seems clear, that the so-called oldest beds of the Highland succession of the Schistose Series of the North-West Highlands are the newest in point of time. The zone of intermixture and metamorphism (in Sutherland) travelled to west from east, and the last beds (schists) to be produced by the earth-movements are those now in contact with the Assynt Series in Durness, Eireboll, and Assynt.

Strikes, dips, and visible sequences are useless in these metamorphic rocks as indices of chronological sequence. The Highlands represent the remains of a degraded mountain-complex the newest of its component ranges being the fossil-bearing beds of the north-west. Some ranges were certainly in existence in the Highlands in Old Red Sandstone time, and some in Silurian time also and there can be little doubt that the Highland area has been the theatre of mountain-making again and again since then. If the same crumpling has taken place over its whole surface as has certainly taken place in Eireboll, its present width must be the merest fraction of its original extent, and the manufacture of its schists and gneisses may have gone on, in some localities, below its surface from pre-Cambrian time to the present without interruption.

At the close of his paper Professor Lapworth embodies his main conclusions under the following heads:-

1. That there is no recognisable chronological sequence (or invariable succession of superposition) in the metamorphic Highland area corresponding to that among sedimentary formations; for the planes dividing the truly metamorphic layers are not planes of deposition, but planes of shearing and cleavage.
2. Many of the Highland schists are composed of Archwan rocks, which have received their present pseudo-bedded arrangement since Ordovician (Silurian) time.
3. What proportion of these schists and gneisses is composed of Archaean, sedimentary, or intrusive materials respectively is in all probability an insoluble question.
4. The gneisses may be either Archaean or possibly formed by intrusion (injection of plutonic rocks) in later ages.
5. The schists may be composed either of crushed Archaean or crushed intrusive rocks, or of a mixture of these with sedimentary materials.
6. The so-called slates may be, according to the locality, either normal slates or crushed rocks, not yet crystallised, of either Archaean, sedimentary, intrusive, or of mixed origin.

In 1885 an important paper was published by Dr. Teall, "On the Metamorphosis of Dolerite into Hornblende-schist",<ref>*Quart. Jour. Geol. Soc.,* xli., p. 133.</ref> as displayed by two more or less parallel dykes in the Archwan gneiss, near the village of Scourie, in Sutherlandshire. From a careful examination of the phenomena presented by the dykes in the field, and by microscopic sections of the rocks, he concluded (1) that the hornblende-schist has been

developed from a dolerite by causes operating after the consolidation of the rock, and that the metamorphosis has been accompanied by a molecular rearrangement of the augite and the felspar; (2) that this molecular rearrangement has in certain cases taken place without the development of foliation; (3) that the plasticity which has led to the development of foliation is that due to high pressures at ordinary temperatures. These deductions have proved of great importance in interpreting many of the phenomena of the Archaean rocks.

The Geological Survey began the detailed mapping of the North-West Highlands in 1883 by tracing out the structure of the Durness–Eireboll region, which was completed in 1884. The results of their operations in the field led to the publication of a Report on the Geology of the North-West of Sutherland", by Messrs. Peach and Horne with an Introduction by Sir Archibald Geikie, then Director-General of the staff, in which there was a frank abandonment of the view advocated by Murchison that the quartzites and limestones of the North-West Highlands are regularly and conformably overlain by the eastern schists. Evidence was adduced to prove the existence of overfolding, reversed faults, and powerful thrusts, whereby the Lewisian gneiss had been made to override the Silurian strata and the eastern schists had been driven from Eireboll for about ten miles westwards to Durness. The various proofs of dynamic metamorphism resulting from these terrestrial movements were briefly indicated, — the development of new divisional planes alike in the Lewisian gneiss, in the pegmatites, and in the Silurian sediments, the obliteration of the old structures and the appearance of new minerals.<ref>Nature vol. xxxi., p. 29, Nov., 1884.</ref>

In 1888 a further report, based on the field notes and maps of Messrs. Peach, Horne, Gunn, Clough, Hinxman and Cadell, and containing detailed descriptions and illustrative sections of the results of the field work southwards to Loch Broom, was communicated to the Geological Society by Sir Archibald Geikie.<ref>*Quart. Jour. Geol. Soc.,* vol. xliv., p. 378.</ref>

Towards the close of 1888 Professor Lapworth announced the important discovery of the *Olenellus* fauna in the west of England.<ref>On the Discovery of the *Olenellus* Fauna in the Lower Cambrian Rocks of Britain", *Geol.* Mag., new series, decade 3, vol. 5, p. 484 (1888).</ref> Fragments of that characteristic genus had been found by him on the flanks of Caer Caradoc in 1885, but too imperfect for description. This determination was placed beyond doubt by the finding further fragments in association with such Lower Cambrian forms *as Kutorgina, Acrothele,* etc. At the end of this paper three tables are given showing the classification of the Cambrian rocks in (1) North-western Europe; (2) the British Islands; (3) Central and South-western Europe, from which it will be seen that he correlated the strata containing *Salterella* and the *Archaeocyathus* fauna in Durness with the Cambrian system.

This correlation was confirmed in 1891 by the discovery of carapaces of *Olenellus* by the Geological Survey in the Fucoid Beds and Serpulite Grit in the Dundonnell Forest between Loch Broom and Loch Maree, which was announced by Sir A. Geikie at the British Association meeting at Cardiff in that year,<ref>*Nature,* vol. xliv., p. 479; *Rep. Brit. Assoc.* for 1891, Trans. of Secs., p. 633.</ref>and described in a paper communicated to the Geological Society in 1892.<ref>The Olenellus Zone in the North-West Highlands of Scotland, *Quart. Jour. Geol. Soc.,* vol. xlviii., p. 227.</ref> This discovery necessarily led to a change in the nomenclature of two of the great rock groups in the North-West Highlands. The series of red sandstones resting unconformably on the Lewisian gneiss were termed Torridonian after Loch Torridon, where Nicol showed that they are typically developed, and the unconformable series of quartzites, Fucoid Beds, Salterella grit, and limestone were now definitely included in the Cambrian system.

In 1894 further additions to the fauna of the *Olenellus* zone were described by Dr. Peach when he recorded the discovery of a new sub-genus, *Olenelloides,* and some new species of trilobites in the Fucoid Beds near Loch Maree.<ref>*Quart. Jour. Geol. Soc.,* vol. 1. p. 661.</ref>

In 1888 Mr H. M. Cadell communicated to the Royal Society of Edinburgh<ref>*Trans. Roy. Soc., Edin.,* vol. xxxv., p. 337.</ref> an account of certain experimental researches as conducted by himself, wherein he reproduced some of the remarkable structures so characteristic of the North-West Highlands, to which further reference will be made in Chapter 32.

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 Dr. Teall, who in 1892<ref>*Trans. Roy. Soc., Edin.,* vol. xxxvii., p. 163.</ref>

described a new type of igneous rock — Borolanite — and in 1900 gave a preliminary account of the petrographical province comprising the plutonic complex of Cnoc na Sroine and Loch Borolan, and the various sills and dykes that traverse the Cambrian and Torridonian sediments, and even the underlying platform of Lewisian gneiss.<ref>Nepheline-Syenite and its Associates in the North-west of Scotland, *Geol. Mag.,* new series, decade 4, vol. vii., p. 385.</ref>