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CHAPTERS ON THE GEOLOGY OF SCOTLAND

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CHAPTERS ON THE GEOLOGY OF SCOTLAND

By the late
BENJAMIN NEEVE PEACH
LL.D., F.R.S.

and the late
JOHN HORNE
LL.D., F.R.S.

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Dedicated to the memory of

CHARLES LAPWORTH, LL.D., F.R.S.

IN RECOGNITION OF HIS

BRILLIANT CONTRIBUTIONS

TO SCOTTISH GEOLOGY

PREFACE

On their retirement from the service of the Geological Survey Drs. Peach and Horne decided to collaborate in the preparation of a book on the Geology of Scotland, intended as their last gift to the science which they had so long and faithfully served. None could have written on this subject with fuller knowledge or deeper insight, but the crowning achievement of their life-long labours was not to be granted. They spent some years in collecting material and in preparing a rough draft to be worked up later into final form. Pressure of other work and failing health, however, delayed their task; Peach died in January 1926, and although Horne carried on alone, for him also the end came, two years later, with the book unfinished.

The volume now published under the title *Chapters on the Geology of Scotland* represents all that they were able to complete. It deals mainly with that part of the country in which their own most original and brilliant researches were carried out, and it includes their final views on some of the most important problems in Scottish geology. Shortly before his death Dr. Horne had approached the Oxford University Press with a view to securing their co-operation in the publication of the book, and on the 30th May 1928 was to have placed in their hands his completed manuscript of the earlier chapters. It was on the morning of the same day that he died.

A *Geology of Scotland* by two such masters of their subject as Peach and Horne would have been an outstanding event in the geological world. Of their own desire that the part they were able to complete should be published there is no question, and in preparing it for the press every care has been taken to see that their wishes have been faithfully carried out. No changes or additions have been made in Chapters I to V, but in the case of Chapters VI and VII, prepared from material left by Dr. Peach, it has been necessary, as explained in the Appendix, to make a few minor adjustments. In carrying these out my co-editors, Mr. E. B. Bailey of the Geological Survey of Scotland and Dr. R. Campbell of Edinburgh University, have everywhere followed Dr. Peach's manuscript as closely as possible.

The text-figures and the Sheet of Horizontal Sections forming Plate XVIII have been prepared by the draughtsmen of the Geological Survey of Scotland under the supervision of Mr. Bailey and Dr. Campbell. Acknowledgements are due to the Controller of H.M. Stationery Office for permission to reproduce a number of illustrations that have already appeared in Geological Survey publications, and for the use of the blocks of Figures 11, 13, 22, and 23; to the Council of the Royal Society of Edinburgh for authority to reproduce Figures 18 and 19 from the Society's *Transactions*, and for the loan of the block of the latter; and to the Council of the Geological Society of Edinburgh for a similar courtesy in regard to Figure 10. The geological and orographical maps forming Plates I and V were prepared originally to accompany the chapter contributed by Peach and Horne to Murray and Pullar's *Bathymetrical Survey of the Scottish Fresh-Water Lochs*, published in 1910, and have been reprinted by Messrs. J. Bartholomew & Son, Edinburgh. The photo-micrograph forming Plate VII (1) has been kindly supplied by Professor T. J. Jehu and Mr. R. M. Craig of Edinburgh University. The other plates are from photographs in the collection of the Geological Survey of Scotland, and with the exception of the view of the Torridonian Hills from Stoer (Plate IV), photographed by Mr. D. Tait, were all taken by Mr. R. Lunn. Those reproduced in Plates III (1), VIII (1), XIII (1), XIV, XV (1) and XVII (1) have already appeared in Geological Survey publications.

Mr. John Mathieson, F.R.S.E., F.R.S.G.S., has kindly checked the spelling of the Gaelic place-names and added a few etymological notes. The Editors desire also to acknowledge the assistance rendered, at all stages of publication, by the authorities of the Oxford University Press.

M. MACGREGOR.

EDINBURGH,

August 1929.

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[1] See also Chapters V and VI. [2] See also Chapters VI and VII.

[1] See also Chapters VI and VII.

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I

PHYSICAL FEATURES OF SCOTLAND IN RELATION TO GEOLOGICAL STRUCTURE

SCOTLAND may be regarded as a mountainous or hilly country, but, in reality, it is a dissected tableland (Pl. II) of no great elevation and of extremely complex geological structure. It is composed mainly of metamorphic rocks and older Palaeozoic strata, the Mesozoic and Tertiary materials being now restricted to limited areas. The Mesozoic sediments must, at one time, have entered largely into the structure of the tableland, but they have been mostly removed by denudation or buried underneath volcanic accumulations of Tertiary age.

From early Palaeozoic, if not from pre-Cambrian, time this region has been periodically subjected to earth movements producing pressures acting from the south-east and north-west. Hence the various groups of rock range across the country in belts with a general north-east and south-west trend. The strata have been thrown into innumerable folds. Great terrestrial displacements have been produced together with normal and reversed faults. This complexity of structure is further increased by the uprise of igneous materials, which either appeared at the surface as lavas and tuffs, or consolidated beneath the surface as intrusive sheets and dykes, or as deep-seated plutonic masses of granite and gabbro. The remarkable volcanic activity in Palaeozoic and Tertiary times is one of the most interesting features in the geological history of the country. It has left impressive memorials in the topography of Scotland.

A careful examination of Scottish topography, especially of the river systems, has led some observers to the conclusion that the existing features have been carved out of a solid block, the upper surface of which sloped in an easterly or south-easterly direction.[1] This view is presented in the following pages.

[1] H. M. Cadell, 'The Dumbartonshire Highlands', *Scot. Geog. Mag.*, vol. ii (1886), p. 337. In this paper the author advanced the hypothesis that the Forth River originally received tributaries from part of the Argyllshire and Dumbartonshire Highlands when the land in the west stood at a relatively higher level than that in the east. The watershed between the east- and west-flowing streams was supposed to have run in a NNE. direction near the eastern margin of Loch Fyne to a point not far to the west of Tyndrum. H. J. Mackinder, *Britain and the British Seas* (1907), pp. 126–33. This volume includes an account of the development of the Scottish river systems. From the evidence the author inferred that 'all the consequent drainage of Scotland seems to have originated on a single, wide-spreading

In early Tertiary times Scotland formed part of a continental area or high plateau continuous with Ireland on the south-west and Scandinavia on the north-east, the surface of which had been reduced to a peneplain by denudation. The youngest rocks entering into this plateau consist of volcanic and plutonic rocks, so prominently developed in the West Highlands, which belong to the oldest division (Eocene) of Tertiary time (Pl. III). Hence its elevation must date from that period. The excavation of the valley systems by the agents of denudation and the development of our Scottish mountains must have been mainly accomplished during the long interval that elapsed between the date of the uplift and the Glacial period. Much of the evidence relating to the topography of the country at the close of the prolonged volcanic activity in Eocene time is, as might be expected, both fragmentary and indefinite, but the available data bearing on the development of the surface features of Scotland can be explained on the foregoing hypothesis.

The physical features of Scotland were largely modified during the Ice Age. Professor R. S. Tarr[1] has called attention in the following terms to the influence of glacial erosion in developing the topographic features of the Scottish Highlands:

'Wherever in the Highlands the ice spread out, and hence became ineffective in erosion, one sees the normal conditions of a maturely dissected land-surface,—normal divides, accordant tributaries, irregularities due to subaerial denudation and even disintegrated rock. Wherever one enters a trough along which he has reason to expect that ice currents moved vigorously, he finds topographic forms normal to ice work, and common in, and confined to, regions where glaciers have been, but utterly out of harmony with the known results of river denudation,—steepened valley walls, truncated spurs, hanging valleys, erased tributaries, lowered cols, and through valleys.'

In Scotland three great planes of denudation can be recognized: (1) the High Plateau or peneplain, varying from 2,000 to 3,000 feet in height with Ben Nevis, the Cairngorm Mountains, and other peaks appearing as monadnocks (Pl. II); (2) the Intermediate Plateau, the upper limit of which is about 1,000 feet (Pl. III, 1); (3) the Continental Shelf, extending to the 100-fathom line at the edge of the

plateau, grained from north-east to south-west, but it is impossible to speak with certainty of the geological date of this departure'. B. N. Peach and J. Horne, 'The Scottish Lakes in Relation to the Geological Features of the Country', *Bathymetrical Survey of the Scottish Fresh-Water Lochs*, Murray and Pullar, vol. i (1910), p. 457. In this contribution the Huttonian principles of earth-sculpture are applied to the evolution of Scottish topography.

[1] 'Glacial Erosion in the Scottish Highlands', *Scot. Geog. Mag.*, vol. xxiv (1908), p. 580.

PLATE II

1. View from Ben Nevis towards Glen Coe.

2. View from Sgùrr nan Clach Geala, Fannich Forest, Ross-shire.

DISSECTED TABLELAND WITH SUMMIT-LEVEL ABOUT
3,000 ft.

Atlantic Rise and the Faroe Channel. Each of these represents a protracted period of denudation with the sea acting in each case as the base-level of erosion.

At the initiation of our river systems, Scotland lay mostly, if not wholly, on the south-east slope of the High Plateau. Across this inclined uplift the consequent[1] rivers drained south-eastwards into the Miocene sea stretching from the north of France to beyond Schleswig-Holstein. The north-west declivity of this land-surface extended to the edge of the Continental Shelf, or, in other words, to the edge of the Atlantic Rise, and was therefore steeper and shorter than the other. Hence the consequent rivers flowing in a north-westerly direction had a greater erosive power than those draining to the south-east. Thus they were able to entrench themselves in valleys, and, by cutting backwards, to encroach on the domain of those flowing to the south-east.

On the mainland of Scotland subsequent denudation has cut the High Plateau into four main blocks:

(1) The North-West Highlands, including the area north-west of Glen More and Loch Linnhe.
(2) The Grampian Highlands, extending from Glen More south-eastwards to the Highland Border between Stonehaven and the Firth of Clyde.
(3) The Central Lowlands, comprising the area between the Highland Border and a line drawn from Dunbar to Girvan.
(4) The Southern Uplands, extending south-eastwards to the English Border and the Solway Firth.

Scotland furnishes remarkable evidence of the intimate relation between the geological structure and the topographical features of the country. For example, the ancient crystalline schists with their associated intrusive masses form the mountainous region of the greater part of the Highlands, while older Palaeozoic strata constitute the Southern Uplands, these rocks being surrounded by younger strata with feebler powers of resistance to the agents of denudation. The Central Lowlands have been carved out of less resistant sedimentary materials of younger Palaeozoic and perhaps of Mesozoic age with volcanic plateaux that form prominent features in the landscape. In like manner the broad features of the Scottish mountains and river valleys have been determined by the relative powers of resistance of the rocks to the denuding agencies.

[1] The terms, *consequent, subsequent,* and *obsequent,* have been applied to rivers by Professor W. M. Davis. Consequent streams run generally at right angles to the axis of an uplifted plateau; subsequent streams flow approximately at right angles to the direction of the consequent rivers; obsequent streams flow in a direction opposite to that of the initial consequent rivers. 'The Development of Certain English Rivers', *Geog. Jour. Lond.*, vol. v (1895), p. 127.

Glen More,[1] separating the North-West Highlands from the Grampian Highlands, coincides in direction with a great fracture in the earth's crust which has caused a downthrow of Old Red Sandstone and Jurassic strata on the south-east side. The Highland Border stretching from Stonehaven to the Firth of Clyde and the northern margin of the Southern Uplands are important structural features which generally coincide with lines of fault resulting in displacements of the strata.

SCULPTURE OF THE NORTH-WEST HIGHLANDS

The North-West Block is divisible into three belts, the physical features of which have been determined by the characters of the rocks and their structural relations. The western belt occupies the tract to the west of a line drawn from Loch Eireboll[2] to Loch Kishorn in the counties of Sutherland and Ross. Its mountains are more or less isolated, forming the crests of the watersheds between the deep valleys whose floors pass below sea-level, having been hollowed out by the obsequent streams and further deepened by later glaciation.

The various groups of rocks entering into the structure of these mountains are given below in descending order according to the original order of succession in geological time:

(C) Cambrian, consisting of quartzites overlain by weaker strata mainly dolomite and limestone.

(B) Torridonian, composed of sandstones, grits, and conglomerates resting unconformably upon Archaean gneiss.

(A) Lewisian, consisting of gneisses and schists, partly of igneous and partly of sedimentary origin, with later intrusive dykes and sills.

The Cambrian quartzites, extending from Eireboll to Kishorn, form a protective covering to the underlying weaker Torridonian grits and sandstones (Pls. VIII, 1, and IX). The overlying Cambrian limestones have readily yielded to the agents of denudation, so that the quartzite, owing to the removal of the dolomite and limestone, usually forms a gentle dip-slope facing the east. Quinag (2,653 feet) and Canisp in Assynt are excellent examples of this type of mountain see Fig. 1).

West of the main outcrop of quartzite in Sutherland and Ross, prominent mountains, composed of Torridonian grits and sandstones, still retain cappings of quartzite which have been isolated by denudation. Excellent examples of these features are to be seen on An

[1] The Gaelic form is *Gleann Mòr na-h Alba*, i.e. the Great Glen of Scotland.

[2] Norse for 'beach village'.

Teallach (3,483 feet) in the Dundonnell Forest, Ross-shire, on Leagach (Liathach 3,456 feet) and Ben Damh (2,958 feet) on either side of Upper Loch Torridon.

Farther west, where the Torridonian sediments have lost their protective covering of quartzite, they assume picturesque mountain forms readily distinguishable from those of the metamorphic rocks of the Highlands. The successive beds, where horizontal or gently inclined, appear like parallel layers of masonry. The mountains rise in terraced escarpments with great mural precipices, and are traversed by numerous vertical joints or faults, features which are well displayed around Upper Loch Torridon and in the wilds of Applecross. Where denudation has reached an advanced stage these sandstone mountains appear as isolated ridges resting on the platform of Archaean gneiss, of which Suilven (2,399 feet) and Stac Polly (2,009 feet) are excellent examples (Pl. IV, 2).

The central belt of the North-West Block forms a narrow strip of country stretching from the eastern shores of Loch Eireboll southwards by Loch Glencoul,[1] Ben More Assynt, and Kinlochewe to Loch Kishorn, where the Lewisian, Torridonian, and Cambrian rocks present extraordinary structures. Within this area the rocks have been folded over each other, piled up, and driven westwards in successive slices (Pls. X, XI). In this belt, where the original sequence of the rocks has been disturbed by earth movement, the Cambrian quartzite acts as a protective agent in retarding the denudation of the less resistant underlying masses and appears as the great mountain-builder. This remarkable feature is seen to advantage in the mountainous region between Loch Glencoul and Ben More Assynt.

The eastern belt of the North-West Highlands includes the remainder of the mountainous ground extending eastwards to Caithness, Glen More, and the Moray Firth. The rocks forming this region are given in the following table in descending order:

(C) Middle Old Red Sandstone, consisting of conglomerates and sandstones resting unconformably upon crystalline schists.

(B) Moine Series, including quartz-biotite-granulites, mica-schists, and muscovite-biotite-gneiss, representing what were originally arenaceous and argillaceous sediments, with intrusions of older foliated granite and epidiorite, and younger granite masses introduced after the foliation of the schists.

(A) Gneisses and schists resembling some of the Lewisian types along the western seaboard of Sutherland and Ross.

The western limit of the eastern belt is defined by the outcrop of the Moine thrust-plane, which is the most easterly of the great post-

[1] Gaelic, *Gleann Couil*, i.e. the glen at the back.

Cambrian displacements between Loch Eireboll and Loch Alsh[1] (Chap. IV). The greater part of this belt is occupied by the crystalline schists of the Moine Series, and gneisses of Lewisian type (Group A) occur only in the centre of the great folds into which the two series have been thrown.

Muscovite-biotite-gneiss of the Moine Series is the great mountain-builder in the eastern belt; while the quartz-biotite-granulites, from their granular texture and regular system of jointing, are more readily disintegrated by atmospheric agencies. Excellent examples of this type of mountain-form are An Riabhachan[2] (3,696 feet) and Sgurr na Lapaich (3,773 feet) on the main watershed of the country south of Achnasheen, where the muscovite-biotite-gneiss caps the lofty summits, while the gneisses of Lewisian type floor the corries. Sgurr a' Mhuilinn, although a minor height (2,845 feet), but a conspicuous feature in the landscape when seen from the Dingwall and Skye railway, has a capping of similar material. The Fannich Mountains illustrate in an effective manner the potency of the muscovite-biotite-gneisses in retarding denudation. Ben Wyvis (3,429 feet) forms a mass of slightly dissected high ground composed of muscovite-biotite-gneiss and siliceous schist, which has been so long isolated that it has developed a radiating drainage system.

In the eastern belt granites of different periods of intrusion occur among the crystalline schists of the Moine Series. A prominent mountain consisting of the newer granite is Ben Loyal (2,504 feet), south of Tongue in Sutherland.

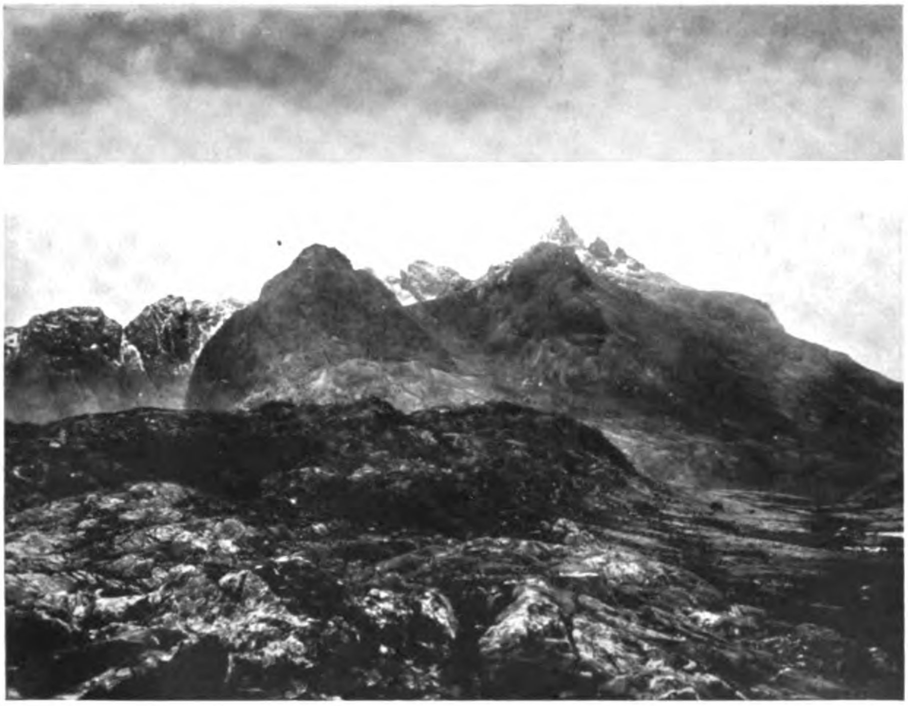
The geological evidence indicates that the grain of the crystalline schists, trending generally north-east and south-west, had little if any influence in determining the trend of the consequent streams. An apparent exception occurs in the Laxford area of Lewisian Gneiss where the strike of the gneiss coincides with the trend of the valleys; but the geological history of that region shows that the valley system must have been initiated at a time when the Lewisian rocks were buried under strata the strike of which ran NNE. and SSW.

Shatter-belts accompanying more or less vertical lines of fault and trending in two directions, one north-west and south-east, and the other north-east and south-west, helped to some extent to produce a drainage system in this northern region. The lines of fracture along Loch Maree and Loch Inchard may be cited as instances of the former, and those extending from Glenelg to Strathconon and along Glen More are striking examples of the latter.

In the eastern portion of the North-West Highlands the grain of the younger strata tended to deflect the rivers from their south-east

[1] Gaelic, *Loch Ailse*. [2] 'The grey or brindled one'.

1. Goatfell, 2,866 ft., a granite mountain in Arran. Middle distance belongs to '1,000-Foot Platform'.



2. Sgùrr nan Gillean 3,167 ft., a gabbro mountain in the Cuillin Hills, Skye.

SCENERY CARVED IN TERTIARY PLUTONIC ROCKS WITH SUMMIT-LEVEL ABOUT 3,000 ft.

course. The arrangement of the Old Red Sandstone and the Mesozoic strata shows not only that they must have entered largely into the structure of the High Plateau, but also that they were thrown into basins intersected by the Glen More fault, the axes of these basins being approximately north-east and south-west. In these weak structures the grain of the rocks became a prominent factor in deflecting the rivers from their south-east course, and, during the period of maximum elevation, in reducing the area to a plain in which the old divides were effaced.

From a study of charts of the sea floor it would appear that two main trunk rivers were established, following the strike of the weak strata and of the shatter-belts produced by the Glen More fault, and by the dislocation skirting part of the Sutherland coast. The more northerly one seems to have flowed parallel to the present south-east coast-line of Sutherland, Caithness, and Orkney, intercepting all the consequent streams as far south as the Dornoch Firth and ultimately draining into the Faroe Channel. The other seems to have run parallel to the coast of Nairn, Moray, Banff, and Aberdeen, following what is probably the strike of the Mesozoic strata, and, at one time, either directly or by means of longitudinal tributaries, tapping all the consequent rivers westwards to Loch Eil.

The Cromarty Firth is evidently the submerged valley of a subsequent stream [1] following the centre of the syncline between the two great shatter-belts which intercepted and deflected all the old consequent streams now draining into it. Again, the main subsequent river between Inverness and Nairn, whose course is now covered by the Moray Firth, tapped and deflected the consequent stream which formerly occupied the site of the Beauly Firth.

Along the eastern portion of the North-West Block, the Intermediate Plateau and the coastal belt are mainly carved out of Old Red Sandstone (Pl. IV, 1), but in certain localities they consist of the old floor of crystalline schists from which the covering of Old Red Sandstone has been removed. Various outlying masses of this formation furnish striking proof of its former extension over this portion of the High Plateau, as for instance, in Strath Vaich, Ross-shire, the heights on either side of Strath Brora, and the Griams in Sutherland.

[1] Hugh Miller (Geological Survey), after mapping the Cromarty district, suggested that the entrance to Cromarty Firth between the Sutors had been excavated by the River Conon in Tertiary time, when the plain of Easter Ross was buried under a thick covering of Old Red Sandstone and Mesozoic strata. He supposed that the valley track of the ancient river extended outside of the Sutors and the plain track along what is now the Moray Firth. 'The Sutors* of Cromarty, a Chapter in Pre-Glacial Geology', *Trans. Invern. Field Club*, vol. iii (1883–8), p. 131.

* The Gaelic is *Na Sùdraichean*, probably meaning 'the tanneries'.

The development of the plain of North Sutherland and Caithness resembles in many respects that of East Sutherland and Easter Ross. Here the weak strata that remain are composed of Old Red Sandstone. A main trunk stream appears to have cut back from the Faroe Channel west of, and parallel to, the long axes of Shetland and Orkney, thence westwards along the strike of the Old Red Sandstone strata by the north coast of Sutherland. The tributaries of this river in some cases followed the pre-Old Red Sandstone valleys in the old floor of crystalline schists, filled with the basement rocks of that formation. As these ancient valleys coincide with the strike of the schists, the streams, by cutting backwards along the grain of the rocks, have been enabled to intersect a great part of the head-waters of the original south-east consequent streams and deflect them towards the north. The River Naver is an excellent example, for it has succeeded in capturing the upper portion of the Helmsdale consequent stream from below Loch Naver to the sources of that river.

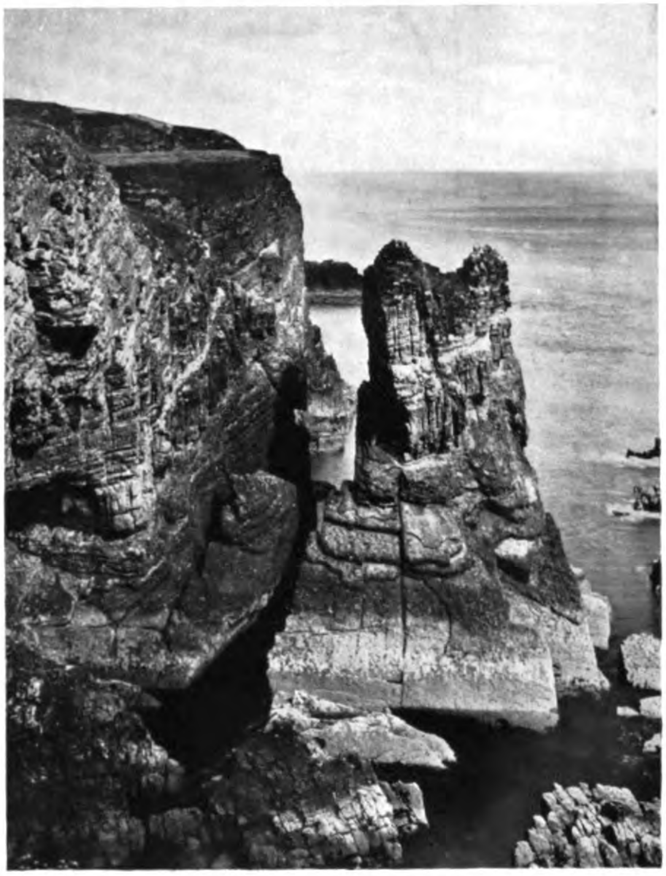
Reference has already been made to the structural evidence suggesting that the subsequent or longitudinal rivers draining into the Moray Firth intercepted the old consequent streams of the North-West Highlands as far west as Loch Eil. While this was in progress, however, the weaker Mesozoic strata overlying the Palaeozoic and schistose rocks in the west were also being removed by rivers cutting back from the Atlantic Rise and forming the plain of the Minch during the period of the production of the Continental Shelf.

Another drainage system seems to have followed the line of the North Channel and reached the shatter-belt of Glen More somewhere about the Firth of Lorne. Along the line of weakness it seems to have cut backwards, intercepting in turn consequent streams of the North-West Block. The order in which the streams were appropriated is probably shown by the decreasing depth of the valleys from west to east. The Sound of Mull, Loch Eil, and Loch Arkaig represent depressions initiated by the old consequent streams of the North-West Highlands.

The prominent physical features in the Outer Hebrides are due to a ridge of Lewisian Gneiss which has been isolated by the denuding action of the western rivers draining to the edge of the Continental Shelf. The depression of the Minch may be partly due to earth movements in Tertiary time, as suggested by Sir H. J. Mackinder.

Skye, which originally formed part of the mainland, has been disconnected by similar processes of denudation and by crustal movements. That island clearly illustrates the three types of scenery that characterize the volcanic and plutonic igneous rocks of Tertiary age in the West Highlands. The basalt plateaux, composed of a succes-

PLATE IV



1. Marine erosion of Middle Old Red Sandstone, Sellifer, S. of Wick.

2. Relict hills of Torridonian sandstone in distance resting on Lewisian gneiss in foreground, from Stoer, Lochinver.

sion of basic lavas with intrusive sheets of dolerite, are represented in the north-west beyond Glen Brittle and Sligachan. The peculiar contours of the great eruptive mass of gabbro are displayed in the Cuillin Hills (the highest summit, Sgurr Alisdair, 3,275 feet), which with their lofty peaks, serrated ridges, and deep clefts are the most striking group of mountains in Scotland (Pl. III, 2). The granite of the Red Hills, weathering with smooth slopes and cones, forms a marked contrast in surface relief to the Cuillins.[1]

SCULPTURE OF THE GRAMPIAN HIGHLANDS

In the Grampian Block the conditions affecting the evolution of the topography of the region resemble to some extent those of the North-West Highlands. A core of crystalline schists, trending north-east and south-west, with plutonic igneous masses, forms the dominant feature, which is surrounded by less resistant sedimentary strata and contemporaneous volcanic rocks.

The rocks entering into the structure of this region are composed of (1) the Moine Series, so prominently developed in the North-West Block; (2) the Dalradian Series, including quartzites, grits, slates, mica-schists, limestones, and dolomites with various schistose rocks of igneous origin; (3) volcanic materials of Lower Old Red Sandstone age, with deep-seated plutonic masses (granite, diorite) belonging mainly to the same period of intrusion. In Pl. II, 1, the middle scenery is carved in group (2) and the background in group (3).

The members of the Moine Series occupy a large area east of Glen More, drained generally by the Spey, Findhorn, the head-waters of the Dee, Tay, Leven, and Spean Rivers. Where not associated with granite masses these crystalline schists do not reach great elevations. They have yielded in a uniform manner to the agents of denudation, and have produced flat-topped, incompletely dissected plateaux, of which the Monadhliath[2] mountains, culminating in Cairn Mairg (3,087 feet), are the best examples. Farther south this plateau forms a large part of the Forests of Gaick and Atholl. In this area the Moine schists are invaded by numerous sheets of porphyrite, which have helped to retard denudation.

The members of the Dalradian Series occupy the greater part of the remainder of the Grampian Block. From the shores of the counties of Banff and Aberdeen they sweep along the southern slopes of the Grampian range to Argyllshire. Prominent members of this series consist of quartzite and quartz-schist, with intervening less

[1] See A. Harker's description of the physical features and scenery of Skye, in 'The Tertiary Igneous Rocks of Skye', *Mem. Geol. Surv.* (1904), p. 434.

[2] Gaelic, *Na Monathliath*, the grey mountains.

resistant schistose and calcareous bands, which, in certain localities, are thrown into great recumbent folds. Along this belt the quartzites are the great mountain-builders and form the principal heights. Conspicuous examples of this type of mountains are Cairnwell (3,059 feet) and Glas Maol[1] (3,502 feet), to the south of Braemar; the peaks of Beinn a' Ghlo (the highest being 3,671 feet), Schiehallion (3,547 feet) and Carn Mairg (3,419 feet), in Perthshire. Beyond the mainland quartzite forms the Paps of Jura and gives rise to lesser eminences in Islay.

The Ben Ledi grits are another prominent member of the Dalradian Series, forming a line of mountains of considerable height, close to and nearly parallel with the Highland Border. They are separated from the Central Highland quartzites by an intermediate belt of weaker schistose strata. Their isolated position on the watersheds between the remnants of the old consequent valleys and their proximity to the Central Lowlands make these mountains conspicuous features in the landscape. They appear in Ben Vorlich (3,224 feet), Ben Ledi (2,875 feet), and Ben Lomond (3,192 feet).

Beyond the consequent valley of Loch Lomond and Glen Falloch there is a group of mountains known as the Arrochar Highlands, composed of altered grits, but with their power of resistance greatly increased owing to contact alteration produced in them by the intrusion of newer acid and basic igneous rocks.

Volcanic and plutonic rocks of Lower Old Red Sandstone age appear on Ben Nevis (4,406 feet), the most elevated ground in Scotland. The greater part of that mountain consists of granite, the higher portion being composed of lavas and volcanic breccias. This volcanic pile forms the splendid line of cliffs facing the deep corrie at the head of Allt a' Mhuilinn.

The geological features of the mountains between Glen Coe and Ben Cruachan resemble those of Ben Nevis. Ben Cruachan (3,689 feet) and Ben Starav (3,541 feet) are composed of granite, and towards the north there is admirably displayed in Glen Coe a vast pile of Lower Old Red Sandstone lavas and agglomerates, associated with sediments of the same age.

In the eastern portion of the Grampian Block great areas of granite enter the High Plateau and form the Cairngorm[2] Mountains (whose highest peaks exceed 4,000 feet), together with Lochnagar (3,768 feet) and Mount Battock (2,555 feet). The Cairngorm mass rises mainly through the members of the Moine Series, while the large intrusions to the south of the Dee pierce the Dalradian sediments.

[1] Gaelic, *A' Glais Mhoail*, the grey bare top.
[2] Gaelic, *A' Càrn Gorm*, the green hill.

The granite of the Cairngorm Mountains, culminating in Ben Macdhui (4,296 feet), has resisted the agents of denudation more successfully than the surrounding schists, and has established a radial drainage system.

The granite mass that forms a picturesque group of mountains in North Arran,[1] rising abruptly from sea-level, may be regarded as an isolated portion of the Grampian Block (Pl. III, 1). Of nearly circular form and with a well-defined boundary, it is intrusive in the Highland schists, except at its eastern margin where it is in contact with Lower Old Red Sandstone strata. This plutonic intrusion is represented in Goat Fell (2,866 feet), Am Binnein (2,172 feet), and Beinn Tarsuinn (2,706 feet).

As might be expected, the remnants of the old consequent streams are best preserved in the centre, and along the south-east slope of the Grampian Highlands, especially along a belt of country several miles broad near the Highland Border. This belt is traversed by consequent or transverse streams flowing towards the south-east, which have been occupied in deepening their valleys.

North of this belt the grain of the rocks has had a powerful influence in modifying the drainage system, so that the Tay-Garry, about the centre of the block, is the only old consequent stream that extends back continuously into the interior of the region. The rivers flowing into the Moray Firth on the north-east, and the sea-lochs and sounds on the west, illustrate the potency of this factor in a remarkable manner.

Remnants of the old drainage system in the form of through valleys, independent of structure, occur on both sides of Loch Linnhe, as described by E. B. Bailey.[2] On the north-west side lie Glen Scaddle, Glen Gour, and Glen Tarbert; on the south-east, Glen Nevis, the Lairigmòr and River Leven valley, and Glen Coe.

The plain on the south-east side of the Moray Firth is due to the removal, in whole or in part, of a succession of comparatively weak strata, separated from each other and from the underlying crystalline schists by planes of denudation and unconformability. The Mesozoic

[1] For description of the physical features of Arran see F. Mort, 'The Sculpture of North Arran', *Scot. Geog. Mag.*, vol. xxx (1914), p. 393. He gives an account of the 1,000-foot platform of marine origin in North Arran, and makes the following suggestions: that Glen Rosa has been deepened by ice action, that the Chalmadale-Sannox depression was initiated when Arran was joined to the mainland, that the deep through valley connecting Easan Biorach and Glen Iorsa is due to ice action. A. Scott, in 'Notes on the Physiography of Arran', *Scot. Geog. Mag.*, vol. xxxiv (1918), p. 90, states that the 1,000-foot platform is probably of Pliocene age, and concludes that 'while the valleys have been broadened by glacial erosion, the spurs being truncated, and the walls steepened to some extent, there is little evidence that there has been any great amount of over-deepening'.

[2] 'The Geology of Ben Nevis and Glen Coe', *Mem. Geol. Surv.* (1916), p. 4.

strata and the Upper Old Red Sandstone form part of the original covering that has now been removed; but the representatives of the Middle Old Red Sandstone had probably the greatest development among the younger formations in this portion of the Grampian Highlands. Indeed, the slope of the country from the High Plateau to the Moray Firth is partly due to the resuscitation of the old floor of crystalline schists on which they were laid down. The apparently abnormal direction of the shore-line, from Fort George to Kinnaird Head, bounding the present plain, is probably due to the strike of the planes of unconformability in that region, at the base of the Trias, and at the base of the Upper and Middle Old Red Sandstone.

The drainage towards the Moray Firth was probably established at an early date. The arrangement of the Old Red Sandstone and the younger strata and the trend of the shatter-belts favoured the action of the subsequent streams, so that the successive divides were broken down, and the disjointed members of the old consequent rivers were made tributaries of the subsequent system of drainage. The Spey is the most striking example, for it seems to have been able to cut backwards so as to intercept the old consequent streams of the North-West Highlands as far west as Loch Eil, though compelled at a later date to yield part of this ground to invaders from the north and west, especially to tributaries of Glen More.

The plain in eastern Aberdeenshire is evidently due to the removal of Old Red Sandstone and probably Mesozoic strata. The Ugie, the Ythan, and the Ury are probably remnants of old consequent streams that crossed this plain.

The Dee valley has been determined largely by the grain of a belt of crystalline schists lying between large masses of granite on either side. The history of the Upper Dee and Don suggests that these rivers were the first to occupy that portion of the High Plateau. For it has been clearly shown that the Feshie captured the head-waters of the Geldie[1] and that the Avon[2] beheaded the Upper Don at Inchrory, thus deflecting drainage at these points towards the Spey. The Tilt, a tributary of the Tay, has also pirated the Tarf from the Dee.[3]

[1] L. W. Hinxman, 'The River Spey', *Scot. Geog. Mag.*, vol. xvii (1901), p. 185; see also A. Bremner, 'Capture of the Geldie by the Feshie', *Scot. Geog. Mag.*, vol. xxxi (1915), p. 589. The latter holds that this case is hardly an example of normal capture in post-Glacial times, but rather of pre-Glacial capture followed by glacial erosion. In connexion with the Spey valley Hinxman inferred from its physical features that an uplift of the land, along an axis running north and south about Grantown, may be the possible cause of the long waste-filled basin of the Spey above Grantown and the rapid fall in the river between Grantown and the sea.

[2] A. W. Gibb, 'The Relation of the Don to the Avon at Inchrory, Banffshire', *Trans. Edin. Geol. Soc.*, vol. ix, part iii (1909), p. 227.

[3] See paper by A. Bremner, 'A Geographical Study of the High Plateau of the

Fiord-valleys. A striking feature of the North-West and Grampian Highlands is the number of fiords or sea-lochs that run inland for miles along the west coast between Cape Wrath and the Firth of Clyde. They are narrow, straight or sinuous in direction, sometimes with prominent walls of rock along their margins, and frequently crossed by barriers at their lower ends, thus presenting in the upper reaches a basin-shaped arrangement.

Different interpretations have been given of the origin of these fiords. This question has been exhaustively discussed in an important volume by Professor J. W. Gregory,[1] who regards fiord-valleys as due to intersecting fractures. He refers to the problem in the following terms:[2]

'The explanation of fiord-valleys as due to intersecting fractures explains the chief facts of their distribution. It explains their restriction to plateau countries, as it is only where wide areas of hard rocks have been uplifted uniformly that they will be shattered by regular intersecting cracks. It also explains their restriction to areas of old rocks, for soft beds, and most of the younger rocks yield by stretching and not by cracking.

'The origin of fiords as a result of uplift and fracture also explains why they so often occur upon western coasts; for the western sides of the continents have generally been uplifted more than the eastern sides, a result probably of the influence of the earth's rotation. The exceptional occurrences of fiords and rias on eastern coasts, as in Greenland, Labrador, and eastern China, are on plateaus of which the eastern continuation has foundered beneath the sea. Otherwise, as in Scandinavia, the British Isles, the Adriatic, North America, South America, and New Zealand fiords occur only on the western shores. A meteorological explanation of this fact has been offered on the ground that the western coasts have the heaviest rainfall and snowfall; but during part of the glacial period the snowfall in Scotland was apparently greatest on the eastern side of the country; and the difference in precipitation is quite insufficient to explain the restriction of lochs to the western coast. In Scandinavia also, during the latter part of the glaciation, the chief snowfall was to the east of the present watershed. . . .

'The gaping cracks were not of the full width of the fiord-valleys. The cracks caused narrow clefts, which have been widened by denudation; water and air enter them and cause the decay of the rocks. Streams remove

South-Eastern Highlands', *Scot. Geog. Mag.*, vol. xxxv (1919), p. 331. Various examples are given of stream capture and of the probable courses of streams, especially in the eastern section, that preceded the present drainage system. He suggests that the hanging valleys in this part of the plateau may be due to various causes: (1) recent, but not necessarily post-Glacial, capture or diversion; (2) deepening of the valley of the tributary stream not keeping pace with that of the valley of the main stream; (3) widening of the main valley by glaciers.

[1] *Nature and Origin of Fiords* (1913). The student should consult this volume as it gives an account of the fiord-systems of the world and their relation to earth-movement.

[2] op. cit., pp. 17–20.

the weakened rock-material and the clefts are gradually widened into river-valleys, and if the country be subsequently glaciated the ice enters the previously formed valleys and completes their formation.'

The available evidence bearing on the origin of fiord-valleys in the West Highlands has led us to regard them as submerged land valleys excavated in the High Plateau by the agents of denudation after the uplift in Tertiary time, but largely modified by ice action during successive stages of the Ice Age. The barriers may be due to solid rock or to the deposition of glacial material. Hence some of the depressions on the landward side of the barriers may represent rock basins, scooped out by ice, as advocated by James Geikie,[1] while others may be impounded by glacial deposits.

It is true that some of the fiord-valleys in the West Highlands run along lines of fracture, but, in our opinion, these have not been the dominant factors in their formation.

SCULPTURE OF THE CENTRAL LOWLANDS

This tract, measuring about 120 miles in length and about 50 miles in breadth, is bounded on the north-west by the Highland fault stretching from Stonehaven to the Firth of Clyde, and on the south-east by the fractures defining the northern margin of the Southern Uplands.

The sediments entering into the structure of the Central Lowlands belong chiefly to the Old Red Sandstone and Carboniferous formations, with which are associated contemporaneous volcanic rocks. The strata are arranged in the form of a compound syncline with subsidiary minor folds, the long axes of which are more or less parallel to the bounding faults, thus giving rise to a prominent grain of the rocks in a north-east and south-west direction. There is ground for maintaining that the Midland Valley may have been partially buried under Permian, Triassic, and younger sediments, which, for the most part, have been removed by denudation.

Along the northern belt of the Central Lowlands the Lower Old Red Sandstone consists of a succession of conglomerates, sandstones, and marls. These sediments are associated with volcanic rocks which are typically developed in the Ochil and Sidlaw Hills, where they form a well-marked arch. Between this volcanic range and the Highland Border the overlying sedimentary strata rest in a trough now represented by Strathmore and the Howe of the Mearns.

The rivers Tay, North Esk, and Bervie traverse the marginal belt of the Highlands in deep consequent valleys, thence cross the plain

[1] *The Great Ice Age*, 3rd ed. (1894), p. 230.

occupied by the Lower Old Red Sandstone sedimentary deposits, and breach the volcanic arch of the Ochil and Sidlaw Hills. Ultimately they joined the trunk river that flowed northwards along the East Coast. It is obvious that at the time of the initiation of these consequent streams Strathmore and the Howe of the Mearns had no existence. There must have been a graded slope from the margin of the Highlands towards the south-east. The behaviour of the rivers on entering the belt of weak strata along Strathmore reveals the processes by which the existing topographical features were developed. Thus the Isla, a subsequent tributary of the Tay, by working north-eastwards along the weaker Lower Old Red Sandstone strata, has captured several of the old consequent streams draining the Highland Plateau from Ericht to the Upper Isla. The deflexion of these waters into the Tay led to the initiation of obsequent streams draining into the Isla on the north-west slope of the Sidlaw Hills, and the formation of wind-gaps across the volcanic arch, of which the hollow traversed by the Dundee and Alyth Junction Railway is a good example.

In like manner the South Esk, which may be regarded as a subsequent tributary of the North Esk, by working south-westwards along the same weak strata, has tapped the old consequent streams of the Highland Plateau as far to the south-west as the Prosen. Again, the Luther Water, a subsequent tributary of the North Esk from the north-east, has captured several minor consequent streams. Wind-gaps resulting from this deflexion are still to be found in that portion of the Sidlaw range, one conspicuous example occurring to the east of Marykirk. Similar phenomena on a smaller scale are observable where the Bervie River crosses the Howe of the Mearns.

The Forth above Stirling has had a similar history to that of the Tay during the period of greatest elevation. It seems to have formed an affluent that passed southwards close by St. Abb's Head to join a stream that drained the Tees, the combined rivers flowing north-eastwards across the plain of the North Sea. The old buried channels of the Forth, and its tributaries the Bonny, the Devon, and the Almond, clearly indicate the greater elevation of the land during the evolution of the present topographical features. Like the other east-flowing streams, the Forth occupied the ground first, and, by working along the weak belts, captured the old consequent rivers of the Grampian Highlands as far west as Loch Long. The streams working inwards from the west subsequently regained part of this drainage area.

The volcanic plateaux in the Midland Valley offered greater resistance to the denuding agents, and hence their outcrops assumed the form of intervening ridges, while the areas occupied by the sediments have been worn down into plains from which rise isolated hills and knobs representing major igneous intrusions and volcanic vents. The Campsie Fells and Kilpatrick Hills, composed of Carboniferous lavas and tuffs, are excellent examples. These hills of circum-denudation are of extreme interest, as they are still breached by the old consequent rivers draining the Highland Plateau and contain wind-gaps indicating the deserted channels of some of these consequent streams. Striking examples of these wind-gaps are represented by the Endrick-Carron hollow across the Campsie Fells, and the Blane-Glazert depression between the Campsie and Kilpatrick Hills.

The Pentland Hills form another ridge of circum-denudation. The course of the River Lyne, which traverses the ridge, furnishes remarkable evidence of the former existence of topographical features that have long since vanished. Rising on the north side of this chain, where it has been beheaded by the tributaries of the Water of Leith, it still flows through these hills as a consequent stream, maintains the old course across West Linton plain, and enters the Southern Uplands in a mature valley. In this chain there are two additional instances of old consequent rivers, the North Esk and its tributary, the Glencorse Water, which, beginning on the northern slope of these hills, cross them in deep valleys. On emerging from the ridge of Lower Old Red Sandstone volcanic rocks the Glencorse Water enters the plain occupied by Carboniferous strata where it has been captured by the Esk and made tributary to the Forth.

Brief allusion may now be made to the probable development of the western portion of the Midland Valley. The trunk river, flowing along the course of the North Channel, worked its way backwards across the Mesozoic strata spread over the plain now occupied by the Firth of Clyde, and captured the old consequent streams up to that now represented by the lower part of Loch Fyne. By following the weak strata of the Upper Old Red Sandstone and the Cementstone Group beneath the Carboniferous volcanic rocks of Renfrewshire, it deflected the old drainage system of the Cowal region and the heights near Loch Lomond which, for a time, flowed eastwards to the Forth.[1] Beyond this point it was probably aided in its recession by taking advantage of one of the hollows established by a tributary of the Forth. On reaching the Clyde basin above Dalmuir it captured the lower portion of the River Clyde, which, as an obsequent stream, had for a time discharged its waters into the Forth.

[1] See H. M. Cadell, 'The Dumbartonshire Highlands', *Scot. Geog. Mag.*, vol. ii (1886), p. 337; H. R. Mill, 'Configuration of the Clyde Sea-Area', *Scot. Geog. Mag.*, vol. iii (1887), p. 15; H. J. Mackinder, 'Britain and the British Seas' (2nd ed., 1907), p. 131; J. W. Gregory, 'The Age of Loch Long and its Relation to the Valley System of Southern Scotland', *Trans. Geol. Soc. Glasg.*, vol. xv, part iii (1916), p. 297.

Sculpture of the Southern Uplands

The Southern Block has a core of Ordovician and Silurian strata with a persistent north-east and south-west strike, pierced by large igneous masses, and more or less surrounded by less resistant sediments, whose remains are traceable across parts of the plateau. Remnants of the old consequent river system established before the isolation of the separate blocks are still preserved in the southern region, of which the Nith is the finest example.

On the south side of the plateau the subsequent or longitudinal system of drainage has been initiated by rivers attacking the weak sediments in flank. Thus the Tweed, working from the east along the less resistant Carboniferous and Upper Old Red Sandstone strata, eventually followed the grain of the Ordovician and Silurian rocks, and by these means was able to intercept all the old consequent drainage westwards to beyond the centre of the plateau. South of the plain of the Merse, remnants of the old transverse streams again appear, for the Coquet, Rede, and Tyne, rising on the north side of the Cheviot range, cross it in well-marked hollows.

The tributary of the North Channel River, flowing along what is now the plain of the Solway Firth, cut its way backwards along the younger sediments. In the higher reaches of this stream the Liddle, by following the grain of the Lower Carboniferous rocks, captured some of the smaller streams belonging to the Tweed system. The Solway-Liddle tributary deflected, from Luce Bay eastwards to the Esk, the old consequent rivers that crossed the Southern Uplands.

On the north side of the plateau the development of the Central Plain has effaced most of the courses of the old consequent streams, but the Doon on the west, and the Clyde in the middle, have maintained the old direction of their valleys by becoming obsequent streams. Frequent reference has been made in geological literature, and particularly by Sir A. Geikie,[1] to the remarkable course of the River Nith. The infant stream rises on the north slope of the Southern Uplands and flows northwards from the Ordovician and Silurian plateau to the plain of Carboniferous strata, along which it runs in an easterly direction for five miles to New Cumnock, where it changes its course to the south-east in the direction of the Solway. The easterly course of the stream above New Cumnock was doubtless determined by a subsequent tributary of the old consequent river that crossed the plateau before the isolation of the four blocks.[2]

[1] *The Scenery of Scotland*, 1865, p. 250; 3rd ed. (1901), p. 332.

[2] See F. Mort, 'The Rivers of South-West Scotland', *Scot. Geog. Mag.*, vol. xxxiv (1918), p. 361. An account is given of three consequent rivers of South-West

As in the Central Lowlands already described, there is evidence to show that in the Southern Uplands the eastward-flowing streams extended farther to the west than at present. That portion of their territory has been captured by rivers draining to the west and south-west. The Tweed may be instanced as an excellent example of these mutations. By means of its tributary now represented by the Biggar Water, it cut backwards till it captured the old consequent Clyde, a large part of which it rendered obsequent. It also appears to have receded far to the west by appropriating the upper portion of this same stream, of which the Duneaton and Douglas Waters were already subsequent tributaries. As the North Channel River and the Lower Clyde cut backwards through weak Carboniferous strata more rapidly than the tributaries of the Tweed among the durable Ordovician and Silurian rocks, they eventually captured the territory which had been temporarily annexed by the Tweed.

Reference should here be made to the flat valley of Biggar which forms the watershed between the Clyde and the Tweed. Sir A. Geikie[1] called attention to this feature and suggested that the Upper Clyde may formerly have flowed down the Tweed valley, thus entering the sea at Berwick instead of at Dumbarton. He stated that 'the origin of this pass across the watershed of the country is probably traceable to the recession of two valleys, and to the subsequent widening of the breach by general atmospheric waste'. Sir H. J. Mackinder[2] discusses this feature in the following terms: 'where the Clyde now emerges from the Southern Uplands, a very small change of level would suffice to turn its torrent head into the Tweed, and this torrent may hence represent the latest capture effected by the usurping Clyde'. He also suggested 'that the Tweed may be the lower course of a river which once had its sources in the Western Highlands'. Professor J. W. Gregory[3] adopted this view, and, after examination of the various sections of the Tweed valley, reached the following conclusions as to the Clyde-Tweed connexion:

'The evidence of the Tweed valley shows that there is nothing to forbid the conclusion that when the land around the Clyde estuary stood at about 1,000 feet above present sea-level, the Clyde discharged eastward to the Tweed. For though middle Tweeddale may in places appear too narrow for the passage of a combined Clyde-Tweed river, the channel has been

Scotland, the Nith, the Ken-Dee, and the Cree, each occupying a valley that traverses the Southern Uplands. It is suggested that before the formation of the Central Lowlands the head-waters of these streams may have been somewhere in the West Highlands.

[1] *The Scenery of Scotland*, 1865, p. 288; 3rd ed. (1901), p. 378.

[2] *Britain and the British Seas* (1902), p. 132.

[3] 'The Tweed Valley and its Relations to the Clyde and Solway', *Scot. Geog. Mag.*, vol. xxxi (1915), p. 478.

blocked by glacial drifts, through which the Tweed is re-excavating its valley; or as at Neidpath, the narrow gorge now used by the river is a younger valley, and the original channel was through a broader gap now blocked by glacial material. In pre-glacial times the Tweed valley was quite large enough to have accommodated the assumed Clyde-Tweed river; and the Clyde had been separated from the Tweed long before Glacial times.'

The feature of special interest in connexion with the topography of the Southern Uplands is the resuscitation of old Palaeozoic land-surfaces in the course of the development of the existing physical features. Thus we find evidence of the existence of a transverse valley system of pre-Upper Old Red Sandstone age of which Lauderdale is the characteristic example. In this ancient hollow sediments of Upper Old Red Sandstone age were laid down which are now being eroded by the Leader Water. Another, but less obvious valley is still buried under sandstones and conglomerates belonging to the same period, stretching across the Eastern Lammermuirs from Longformacus to Dunbar.

Nithsdale and Loch Ryan are instances of pre-Carboniferous hollows, for they are still floored in part by Carboniferous strata which are remnants of more extensive deposits. In the case of Loch Ryan the Carboniferous rocks must have undergone considerable denudation before the deposition of the overlying red sandstones of Permian or Triassic age. Annandale furnishes striking evidence of a valley system dating back to Palaeozoic time, as the breccias (Permian or Triassic) which floor the present valley near Moffat contain blocks of fossiliferous Lower Carboniferous strata that once filled these depressions. The hollow of Eskdalemuir is another example, for the deep staining of the Silurian rocks points to the removal by denudation of red strata from that area. Again, in the Abington region, the outlying patches of Carboniferous strata and breccia of Permian or Triassic age rest unconformably on the old Silurian floor in such a manner as to suggest that the Clyde took advantage of these weak sediments while cutting backwards as an obsequent stream.

Along the western edge of the Upper Old Red Sandstone area south of Melrose there are examples of a secondary system of smaller valleys following the grain of the Silurian rocks, which contain outliers of Upper Old Red Sandstone. Recent observations point to the existence of such sediments in the valley of the Ettrick far to the west of Selkirk.

Large flat-topped remnants of the High Plateau are represented by Broad Law (2,754 feet), Dollar Law (2,680 feet), and Dun Rig (2,433 feet), which are encircled by the Tweed and its tributaries that cut backwards in deep valleys terminating in coomb-shaped hollows.

Hart Fell (2,651 feet) and White Coomb (2,695 feet) form a more dissected portion of the same plateau now separated from it by the valleys of the Megget and Talla.

In the south-western portion of the uplands various granite intrusions, including the Loch Doon, Cairnsmore of Fleet, Cairnsmore of Dee, and Criffel masses, give rise to characteristic mountain-forms and more or less rugged features. Of these the most important is the Loch Doon mass on account of its relations to the surrounding strata and the light which it throws on mountain-building in that region. The granite forms a central cauldron-shaped area, bounded on all sides by high ground, composed of Ordovician sediments which have been altered and hardened by contact with the igneous material. The western range includes the Merrick (2,764 feet), the most elevated ground in the Southern Uplands, while the Kells range flanks the mass on the eastern side. As we recede from the granite margin and the contact phenomena associated with it, the Merrick range slopes rapidly downwards to the undulating low plateau beyond the Minnoch Water, and the Kells range to the low ground in the valley of the Ken. The rugged central region of granite is drained by four streams which have breached the ring of altered sedimentary rocks, viz. the Doon and the Girvan flowing towards the north, and the Dee and the Trool running towards the south.

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II

PRE-CAMBRIAN ROCKS

LEWISIAN GNEISS (ARCHAEAN)

THE metamorphic rocks of Scotland are extensively developed throughout the Highlands, in the long chain of the Outer Hebrides, and in the Shetland Isles. Notwithstanding this wide distribution, their stratigraphical position is only clearly defined along the western margin of the counties of Sutherland and Ross. In that region three rock groups occur in consecutive order from west to east: first,

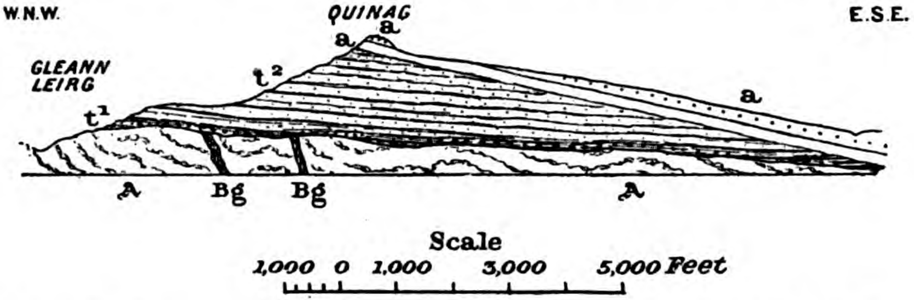


FIG. 1. Section across Quinag, near Loch Assynt, showing stratigraphical relations of Lewisian, Torridonian, and Cambrian. Cambrian: a (unstippled) Basal Quartzite; a (stippled) Pipe-rock. Torridonian: t¹ Diabaig Group; t² Applecross Group. Lewisian: A Gneiss; Bg Basic Dykes. (*Based on Fig.* 31, '*N.W. Highland Memoir*'.)

the Lewisian or Archaean Gneiss; second, the Torridon Sandstone; third, the Cambrian formation with its lowest fossiliferous platform, the *Olenellus* zone, which has been traced for more than one hundred miles from the north coast of Sutherland to Skye.

The field relations of these rock groups are clearly displayed in numerous sections on sea cliffs and bare mountain slopes. Between the Lewisian Gneiss and the Torridonian grits and sandstones there is a great stratigraphical break which indicates a vast lapse of time (Pl. VIII, 2). The Cambrian strata rest unconformably alike on the Lewisian Gneiss and the Torridon Sandstone, thereby implying the removal by denudation of Torridonian sediments before the marine deposits of Cambrian time were laid down (Pls. VIII, 1, and IX). By such evidence the pre-Cambrian age of the Lewisian Gneiss and Torridon Sandstone on the mainland has been proved beyond doubt.

The evidence regarding the stratigraphical position of the metamorphic rocks throughout the remainder of the Highlands rests upon a very different basis. For the continuity of the geological record is interrupted at the top of the Cambrian limestone at Durness by the great series of post-Cambrian displacements, which form the most striking feature in the geological structure of the North-West Highlands. East of the Moine Thrust—the most easterly of the main lines of displacement—we enter the domain of these metamorphic rocks, extending south-eastwards to the Highland border between Stonehaven and the Firth of Clyde. This region, comprising an area of about 11,000 square miles, teems with controversial points. The age, the order of succession, and the field relations of many of these rocks still give rise to keen discussion and renewed investigation. Since 1884 they have been generally regarded as pre-Cambrian with the exception of certain sediments along the eastern margin of the Highlands (Stonehaven, Aberfoyle), which have yielded fossils probably of Upper Cambrian and Lower Ordovician age. In the sequel attention will be directed to some of the interpretations that have been advanced in connexion with these problems.

WESTERN SEABOARD OF SUTHERLAND AND ROSS

The oldest gneisses in the North-West Highlands, whose stratigraphical position was recognized by Macculloch[1] and Hay Cunningham,[2] were first termed Fundamental Gneiss by Murchison.[3] He subsequently adopted the term Laurentian on the suggestion of Sir Andrew Ramsay, who assured him that these rocks must be the equivalents of those forming the Laurentian system established by Sir William Logan in Canada. This suggestion was made by Ramsay[4] in 1859, after his traverses in Canada under the guidance of Logan, and during a joint examination with Murchison of the oldest gneisses in the west of Sutherland.

The Laurentian gneisses were regarded by Logan as metamorphosed sediments forming the lowest division of the pre-Cambrian rocks in Canada. The discovery by Professor Lawson[5] that part of the Laurentian gneiss consists of igneous material intrusive into rocks of sedimentary origin destroyed the value of this term for purposes of classification of similar rock masses in other lands.

[1] *A Description of the Western Islands of Scotland* (1819), vol. ii, pp. 89, 95, and vol. iii, with plates and maps, pp. 51, 52.

[2] 'Geognostical Account of the County of Sutherland', *Trans. Highland and Agric. Soc.*, vol. xiii and n.s., vol. vii (1841), p. 73.

[3] 'On the Succession of the Older Rocks in the Northernmost Counties of Scotland,' *Quart. Jour. Geol. Soc.*, vol. xv (1859), p. 359; also 'Supplementary Observations', *ibid.*, vol. xvi (1860), p. 216.

[4] *Siluria*, 4th ed. (1867), p. 171.

[5] 'On the Geology of the Rainy Lake Region', *Geol. Surv. Canada Ann. Rep. for 1887–88*, New Series, vol. iii, part i (1889), F. See also 'The Archaean Geology of Rainy Lake Re-studied', *Geol. Surv. Canada Geol. Series, Mem.* 40, *No.* 24, (1913).

The term Lewisian Gneiss has been applied by the Geological Survey to the whole assemblage of rocks forming the floor on which the Torridonian sediments were laid down. These ancient gneisses and the metamorphic rocks throughout the Highlands were considered by Hutton to be sedimentary formations which had been rendered crystalline by the action of heat. This view was adopted by Macculloch, by Murchison and A. Geikie,[1] and by other observers who had studied the Highland schists. In the light of recent researches this interpretation, with certain exceptions, is no longer applicable to the ancient gneisses along the western seaboard of Sutherland and Ross.

Rocks

The detailed mapping of that region by the Geological Survey has shown that the rocks are divisible into (1) a Fundamental Complex, consisting mainly of gneisses that have affinities, both chemically and mineralogically, with plutonic igneous products, and partly of crystalline schists which are evidently of sedimentary origin; (2) a series of igneous rocks intrusive in that complex in the form of dykes, sills, and irregular veins.

Sir J. J. H. Teall[2] has pointed out that the members of the complex, possessing affinities with plutonic igneous products, are mainly composed of olivine, augite (including diallage), hypersthene, hornblende, biotite, plagioclase, microcline, orthoclase, and quartz,—minerals which enter into the composition of peridotites, gabbros, diorites, and granites. He adopted the following classification, based mainly on their mineralogical composition, but partly on their structure:

I. Rocks composed of ferro-magnesian minerals without felspar or quartz, comprising (*a*) peridotites, serpentines, pyroxenites and banded hornblende-rocks, (*b*) hornblende-rocks not included in the banded series.

II. Rocks in which pyroxene is the dominant ferro-magnesian constituent, felspar always and quartz sometimes present. These include (*a*) rocks without quartz, such as pyroxene-granulite, (*b*) rocks with quartz, of which augite-gneiss is a type.

III. Rocks in which hornblende is the chief ferro-magnesian mineral, felspar being almost always present. These include (*a*) rocks without quartz or nearly so, and basic in composition, either massive (epidote-amphibolite or garnet-amphibolite) or schistose (hornblende-schist or -gneiss), and (*b*) rocks with quartz of which granular hornblende-gneiss is an excellent example.

[1] 'On the Coincidence between Stratification and Foliation in the Crystalline Rocks of the Scottish Highlands', *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 232.

[2] 'Geological Structure of the North-West Highlands of Scotland', *Mem. Geol. Surv.* (1907), p. 41.

IV. Rocks in which biotite is the dominant ferro-magnesian constituent, both felspar and quartz being present, comprising biotite-gneiss proper and granulitic biotite-gneiss.

V. Rocks in which biotite and muscovite occur, together with quartz and felspar; muscovite-biotite-gneisses.

The crystalline schists, representing altered sedimentary rocks, include dark-brown platy schist, silvery mica-schist with garnets, granulitic biotite-schist, graphitic schists, quartz-magnetite-granulites; and various calcareous rocks, such as limestone, dolomite, cipolin with tremolite, chlorite, garnet, and epidote. These rocks have only a limited development, being restricted mainly to the district of Loch Maree. Hence they have been termed the Loch Maree sedimentary series.

The igneous rocks intrusive in the Fundamental Complex have been arranged by Teall in four groups: (1) ultrabasic, picrites, &c.; (2) basic, including hyperite, gabbro, diabase, and epidiorite; (3) microcline-mica-rocks and biotite-diorite; (4) granite and pegmatite, which were the last in the order of intrusion.

After the eruption of the ultrabasic, basic, and intermediate dykes the Lewisian Gneiss area was subjected in pre-Torridonian time to earth-movements which affected the members of the Fundamental Complex and later intrusions. These earth-stresses gave rise to rapid plication of the strata and to lines of disruption or shear-zones, accompanied or followed by recrystallization of the original constituents, development of foliation, and occasional mylonization of the rocks.

Distribution of the Fundamental Complex

The distribution of the members of the Fundamental Complex indicates that certain districts are characterized by distinctive rock-types which throw light on the history of the Lewisian Gneiss and on the modifications of the later intrusions. Thus the region has been divided by the Geological Survey into three districts, the northern extending from Cape Wrath to Loch Laxford, the central from Laxford to Loch Broom, and the southern from Gruinard Bay to Loch Torridon and Raasay.

i. *Central District from Laxford to Loch Broom.*

The evidence furnished by the Central District is of prime importance because there the original gneisses bear a close resemblance to plutonic igneous rocks, the intrusive character of the numerous basic and ultrabasic dykes is apparent, and the subsequent deformation of gneiss and dykes is remarkably clear.

Fundamental Complex. The characteristic feature of that part of the Central District stretching from Scourie to Loch Broom is the great development of grey quartz-pyroxene-gneisses which appear as massive rudely foliated igneous rocks or as banded gneisses in which the constituents have a parallel or wavy arrangement. In addition to the pyroxenes this type contains hornblende and biotite as original constituents. These gneisses are readily recognized by the abundance of blue or opalescent quartz, the carious weathering of the surface due to the decomposition of the felspar and the ferro-magnesian constituents, and the projecting network of quartz. The ultrabasic rocks (pyroxenites, hornblendites) generally form lenticles, and the basic masses (pyroxene-granulites, garnet-amphibolites) have frequently a rude foliation which usually coincides with that of the contiguous pyroxene-gneiss. No trace of chilled edges has been found between the successive members of the complex, but the examination of the rocks in the field and under the microscope has established the general law that the acid portions are later than the basic. Where not deformed by pre-Torridonian movements they are arranged in gentle anticlines and synclines, the axes of which usually run north-north-east and south-south-west or north-east and south-west, the outcrops of the successive bands forming parallel escarpments.

Probable Origin of the Banded Structures in the Original Gneisses. A conspicuous feature of the pyroxene-gneiss between Scourie and Lochinver is the contortion and overfolding of the respective folia, which are truncated by planes oblique to the minute folia. These planes are not accompanied by granulitization. In 1888[1] we ascribed these phenomena to a gradual movement and piling up of the materials as the plutonic rocks underwent enormous pressure when in a solid form. But the researches of Geikie and Teall on the banded structures of Tertiary gabbros in Skye have led us to abandon this interpretation. In their joint paper describing these researches, they advance the hypothesis that the structures were there produced by the deformation of the molten mass during the intrusion of a heterogeneous magma. They point out the close resemblance of the banded structures in some of the original gneisses between Scourie and Lochinver to those in the Tertiary gabbros in Skye, and they regard it as probable that they have arisen from the same conditions. They make the following suggestive statements:[2]

'One great difficulty with which the geologist has to contend in his attempt to unravel the complicated story of the Lewisian Gneiss, is that of

[1] 'Report on the Recent Work of the Geological Survey in the North-West Highlands of Scotland', *Quart. Jour. Geol. Soc.*, vol. xliv (1888), p. 389.

[2] 'On the Banded Structures of some Tertiary Gabbros in the Isle of Skye', *Quart. Jour. Geol. Soc.*, vol. l (1894), pp. 658, 659. See also in this connexion A. Harker in 'The Tertiary Igneous Rocks of Skye', *Mem. Geol. Surv.* (1904), pp. 90, 117.

separating the effects due to causes operating before or during the consolidation of igneous magmas from those due to dynamic action operating upon the rocks after consolidation.' They infer 'that much of the banding among the old gneisses, as distinguished from mere foliation, which has been ascribed to late mechanical deformation, may be an original structure due to the conditions in which the igneous magma was erupted and consolidated. In view, however, of the undoubted evidence of secondary dynamic action in many regions, and in the absence at present of any well-established criteria by which we can in all cases discriminate between original and secondary structures, we are not yet in a position to define the exact limits within which the hypothesis of the intrusion of heterogeneous magmas is applicable to the explanation of the structures of the Lewisian Gneiss.'

Later Basic and Ultrabasic Intrusions. The relation of the basic and ultrabasic dykes to the Fundamental Complex in the Central District shows that at the time of their intrusion the complex had reached a higher zone of the earth's crust than that at which the original gneisses had been formed. Tension strains in the complex then gave rise to a series of fissures, trending generally in a north-west and south-east direction, now filled by the basic dykes. At a later date tension strains produced fissures, running generally WNW. and ESE., now occupied by the ultrabasic dykes (picrites). These intrusions, which are easily traceable across the low plateau between the western shore and the base of the Torridonian and Cambrian escarpments, present chilled margins in contact with the gneiss. Teall showed that the basic group in the Central District included the following petrographical types: olivine-norite, hyperite, gabbro, diabase, enstatite-diabase and epidiorite, which are typically represented in the Assynt region.

Pre-Torridonian Movements. With few exceptions the pre-Torridonian lines of movement run in two main directions: nearly north-west and south-east, and nearly east and west. They give rise to shear-zones, varying generally in width from a few feet to one hundred and fifty yards. Those running roughly parallel with the basic dykes and coincident with them for long distances are perhaps the earlier of the two series. In some instances the north-westerly disruption lines are unconnected with dykes. They are usually accompanied by folding and granulitization of the gneisses along axial planes trending in a similar direction. The basic dykes are partly or wholly metamorphosed into hornblende-schist. The hornblende crystals always lie parallel to the foliation planes of the schistose dykes, their general direction being the direction of stretching on these planes. The ultrabasic dykes pass, according to Teall, into talc-gedrite-siderite-schist.

As the east and west disruption lines are approached, the original gneisses gradually change their strike and dip, and are sharply plicated along axial planes more or less parallel with the trend of the shear-zone. Coincident with this folding, important changes are effected in the mineral constituents along the early banding planes of the gneiss. Within the shear-zones new foliation planes are developed and the minerals are granulitized. Teall has pointed out that the pyroxene passes into hornblende, the quartz loses its opalescence, and the hornblende is altered into biotite. The reconstructed rocks appear as granulitic hornblende-gneiss and fine granulitic biotite-gneiss with which veins and lenticles of quartz are often associated.

The modifications of the basic dykes are no less marked. Where they are crossed by east and west lines of movement they are deflected and thinned, sometimes to such an extent that dykes from fifty to sixty yards in breadth are reduced to a few feet. Under these conditions they merge into hornblende-schist. Their outcrops are shifted as if by normal faults. Within the shear-zones they are occasionally severed into detached lenticles of hornblende-schist, arranged parallel to the foliation planes of the reconstructed gneiss by which they are surrounded.

In the Lochinver district examples of the north-west movements are to be seen along a narrow belt extending from the base of Canisp to the shore between Lochinver and Stoer, where the lines of disruption occur close together and affect the gneiss with the basic and ultrabasic dykes. Within this belt only phacoidal masses of the original gneisses and dykes are left comparatively undeformed. The modifications caused by the east and west movements are displayed at intervals along a belt of country stretching for several miles east from Stoer. But, as the disruption lines there are some distance from each other, the characteristic phenomena are not seen to the best advantage.

The clearest examples of the pre-Torridonian movements are to be found in the tract between Kylesku and Laxford, where they were mapped in great detail by Clough. Numerous well-defined east and west lines of movement traverse the region between Kylesku and Scourie, while the north-west disruption lines are abundant between Scourie and Laxford (One-inch Geological Map of Scotland, Sheet 107).

The evidence for the metamorphism of dolerite into hornblende-schist was obtained by Teall in a basic dyke on the north side of Scourie Bay. His conclusions have been abundantly confirmed by the Geological Survey throughout the Lewisian Gneiss area where basic dykes have been affected by pre-Torridonian movements. Regarding the nature of the foliation, he stated in his first paper that 'the phenomena of the Scourie dyke appear to show that the plasticity which has led to the origin of the foliation is that due to high pressure at ordinary temperatures, rather than to high temperatures at ordinary pressures'.[1] In a later communication[2] he modified his first suggestion that the deformation took place at ordinary temperatures, and adopted the view that it was developed at comparatively low temperatures. He clearly states that he does not limit the term dynamic metamorphism to rock deformation accompanied merely by fracture and crushing of the minerals. Such a limited interpretation would not explain the phenomena of the Scourie dyke.

Later Acid Intrusions. Along the northern margin of the Central District between Scourie and Laxford we traverse an area where the acid intrusions, which are later than the basic dykes, increase rapidly in number and usher in some of the characteristic rock-types of the Northern District.

North of Scourie there is a belt, about two miles broad, where the north-westerly lines of movement are close together (south-west part of Fig. 2). Here the gneisses have been thrown into sharp folds with axial planes trending WNW. and dipping steeply WSW. The rocks of the complex appear in a more or less granulitic condition, the basic dykes pass into hornblende-schists and frequently form detached lenticles in the reconstructed gneiss. In this area thin bands of foliated granite occur within basic dykes, both having common foliation planes.

Northwards near Laxford and Loch Stack, in a strip of country averaging a mile in width, the Fundamental Complex is invaded by abundant sills and dykes of foliated granite and pegmatite striking WNW., that is more or less parallel with the foliation of the gneisses of the complex (NE. part of Fig. 2). The dominant minerals of the granite are oligoclase, microcline, and quartz, with biotite and rarely hornblende as ferro-magnesian constituents. The intrusive magma was homogeneous and the parallel structure is due to the orientation of the minerals and mainly to the biotites. From the evidence in the field Clough inferred that earth-stresses during folding determined the direction of the foliation in the granite-gneisses. He thought it could not be due to flow structure, because in many instances it crosses the sides of these intrusions and affects the contiguous gneiss. It is worthy of note that the folds in this narrow belt are not accompanied by distinct granulitization. The hornblende-gneisses are granular. The absence of definite lines of thrust and of zones of granulitization suggested to Clough that at the time the shear-zones

[1] 'The Metamorphosis of Dolerite into Hornblende-schist', *Quart. Jour. Geol. Soc.*, vol. xli (1885), p. 141.

[2] 'Dynamic Metamorphism', *Proc. Geol. Assoc.*, vol. xxix, part 1 (1918), p. 1.

between Scourie and Lochinver were being formed the gneisses immediately to the south of Laxford and Loch Stack were comparatively plastic.[1]

The behaviour of the pegmatites, associated with the granite-gneisses in this belt, indicates that the pressure which gave rise to the foliation must have been intermittent. Most of the coarse pegmatites are not foliated, but some of them are cut by bands of granite-gneiss, which are intersected in turn by later pegmatites. Sir J. S. Flett's description of the Lizard metamorphism seems to be applicable to these phenomena:[2] 'It is perfectly clear that the rocks were not all foliated at the same time, or by one great epoch of movement, but that the metamorphism was going on hand in hand with the intrusion of the successive members of the complex.'

ii. *The Northern District from Cape Wrath*[3] *to Laxford.*[4]

The types of Lewisian Gneiss between Laxford and Cape Wrath (Pl. VI) differ in a marked degree from the prevalent types in the Central District. The grey quartz-pyroxene-gneisses which are so prominently developed in the Fundamental Complex between Scourie and Lochinver are here absent. They are replaced by granular hornblende-gneiss and biotite-gneiss. The normal types of the basic dykes do not occur, but they may be represented in certain localities by bands of hornblende-gneiss or -schist traceable only for short distances. Definite shear-zones, resembling those in the Scourie and Lochinver areas, have not been recorded. Perhaps the most characteristic feature of this district is the abundant intrusions of granite and pegmatite which frequently isolate in lenticles the members of the complex. Hence in the field it is sometimes difficult to separate the later foliated granites or granite-gneisses from the original biotite-gneiss.

Fundamental Complex. In the peninsula between Loch Laxford and Loch Inchard the granular hornblende- and biotite-gneisses are associated with early basic masses, composed of black hornblende and biotite, which form knots, lenticles, and bands, varying in width from a few inches to one hundred yards. Occasional strips of hornblende-schist, which may possibly represent dykes, have been noted, but they have no general north-west trend. In some localities they cut the adjacent gneiss, but in others their intrusive character is not apparent. Lithologically they differ from the hornblende-schists of

[1] 'The Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), p. 127.
[2] 'The Geology of the Lizard and Meneage', *Mem. Geol. Surv.* (1912), p. 22.
[3] Cape Wrath is in Gaelic *Am Parbh*, from Norse *Hraf*, turning-point.
[4] Norse, salmon fiord.

PLATE VI

SEA-CLIFF OF LEWISIAN ORTHOGNEISS

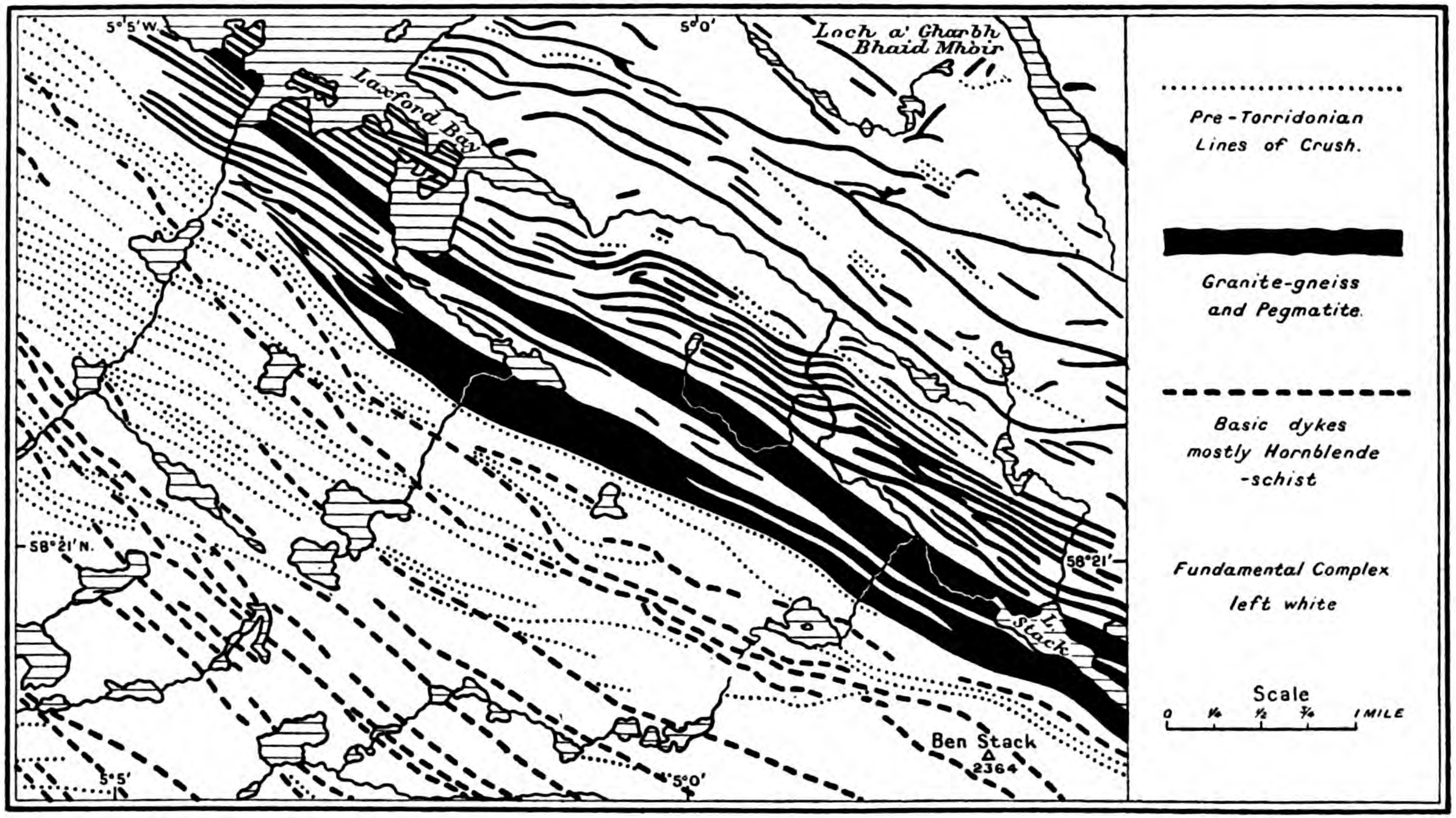


FIG. 2. Map of Lewisian in the Laxford district north of Loch Glencoul. (*After C. T. Clough in Sheet 107, Geol. Surv. One-inch Map Scot.*)

the Scourie dyke type. They are less fissile and schistose and contain hornblende crystals of stouter form (short crystallization). Occasionally a linear foliation or rod-structure replaces the plane-parallel foliation.

In the coast sections of Cape Wrath and the Kyle of Durness the granular hornblende- and biotite-gneisses are associated with basic masses, which have common planes of foliation with the gneiss, and share in the sharp plications of the members of the complex. These probably indicate early basic portions of the Lewisian Gneiss. On Beinn an Amair—a hill on the west side of the Kyle of Durness—where the hornblende- and biotite-gneisses of the complex are mainly granulitic, several narrow dyke-like bands of hornblende-schist occur, trending WNW. and ESE. These cross the foliation planes of the gneiss and may represent later basic intrusions.

An exceptional type[1] in the Fundamental Complex has been recorded by Teall at Polla near the head of Loch Eireboll, where the Lewisian Gneiss has been exposed by the denudation of the overlying cake of Cambrian quartzite. From his description it appears that it is essentially composed of microcline and a green pyroxene with hornblende, sphene, apatite, quartz, and magnetite as accessories. The green pyroxene is probably an aegirine-augite, and the rock, if igneous, would be termed augite-syenite.

Throughout the greater part of this district the rocks of the Fundamental Complex have been folded on vertical or highly inclined axial planes which strike north-west and south-east. Sometimes the folds are recumbent. A highly inclined foliation, trending in a similar direction, accompanies the sharp plication, which obtains also in those areas where the individual bands of gneiss can be traced as gently inclined layers.

Later Acid Intrusions. The lithological types of the later acid intrusions in the Northern District closely resemble those already described south of Laxford. In the tract immediately to the north of Loch Stack and Laxford they appear as nearly vertical sills and dykes of granite, most of which are foliated. The foliation of the granite-gneisses is usually parallel to the sides of the intrusions, but in some cases it crosses the margins and is continuous with the second foliation of the early gneisses of the complex. The sills also occur as gently-inclined sheets cutting the vertical bands of the older gneiss, the foliation in these sills being continuous with a later foliation in the contiguous gneiss. Clough records examples of the plication of the early gneiss and some thin granite sills showing the common

[1] 'The Geological Structure of the North-West Highlands,' *Mem. Geol. Surv.* (1907), p. 53.

foliation of the gneiss and granite, almost parallel to the axial planes of the fold and crossing the margins of the sills. In these instances the development of the common planes of schistosity was evidently subsequent to the folding.

Pegmatites with microcline as the characteristic felspar are common in the tract to the north of Loch Stack and Laxford, where they are of variable thickness, sometimes forming broad bands, sometimes appearing as lenticles connected by narrow veins. Most of them are parallel to the first foliation planes of the gneiss and share in the subsequent folding, while some of them cut across the banded gneisses and the hornblende-schists. In this area also it is evident that all the pegmatites were not intruded simultaneously as some of them are crossed by the foliated granites, the latter being cut in turn by later pegmatites. These phenomena, indicating the complicated relation of the pegmatites to the granite sills and dykes, suggest that the earth-stresses were intermittent during the successive eruptions of the acid igneous materials.

In the neighbourhood of Cape Wrath, on the west side of the Kyle of Durness, and on the Archaean ridge between the mouth of Loch Eireboll and the Durness Cambrian basin, the later acid intrusions are abundant. At the two former localities the later granites are not foliated but show a slight linear arrangement of the minerals probably due to fluxion structure. On the north-west slope of Beinn Ceannabeinne—a hill two miles south-east of Durness village—the development of pegmatites is remarkable. A belt of veins, about a quarter of a mile broad, with few inclusions of the early gneisses, is there exposed. They have a persistent north-west strike and are parallel with the banding of the gneisses of the complex.[1]

Where the later acid intrusions in the Northern District have a limited development the members of the Fundamental Complex are mainly granulitic, as on Beinn an Amair, but where they are abundant the early gneisses are granular. Peach has suggested that the granular crystallization may be due in some measure to the thermal metamorphism induced by the widespread eruptions of the later granites and pegmatites.

iii. *The Southern District from Gruinard Bay to Loch Torridon and Raasay.*

In this district the members of the Lewisian Gneiss Complex present the following characteristic features: (1) a marked absence or comparative absence of the pyroxene-gneiss with blue quartz; (2)

[1] 'Special Reports on the Mineral Resources of Great Britain', vol. v, *Mem. Geol. Surv.* (1917), p. 9.

a great development of augen-gneiss, containing 'eyes' of felspar, with biotite as the dominant ferro-magnesian constituent; (3) the presence in certain localities of granular hornblende-gneiss, hornblende-biotite-gneiss and biotite-gneiss, resembling types between Laxford and Cape Wrath; (4) a great series of basic dykes either in the massive form with clear intrusive junctions, or as hornblende-schists, which in places are difficult to separate from the complex; (5) conclusive evidence of pre-Torridonian movements which developed new structures alike in gneiss and dykes; (6) well-defined belts of rocks of sedimentary origin with igneous intrusions in the form of sills of hornblende-schist; (7) the occurrence of irregular veins of pegmatite which traverse the gneiss and basic dykes.

The Loch Maree portion of the Southern District is of exceptional interest owing partly to the association of crystalline schists of sedimentary origin (paragneisses) with gneisses of igneous origin (orthogneisses), and partly to the four great flexures into which these groups have been thrown by pre-Torridonian movements. To simplify the description of the complicated structure of this region reference may here be made in advance to these broad folds. Their long axes, which are more or less parallel, trend north-west and south-east. The schists of sedimentary origin form the Letterewe syncline north of Loch Maree and the Gairloch syncline south of that loch. Between these trough-shaped folds lies the Tollie anticline, composed of the Fundamental Complex and basic dykes, while to the north-east of the Letterewe syncline is situated the Carnmore and Fionn Loch anticline, consisting of similar material (One-inch Geological Map of Scotland, Sheets 91, 92).

Fundamental Complex. In the Gruinard area the complex contains a limited development of ultrabasic rocks (peridotites, pyroxenites, hornblendites) and early basic masses, comprising diorites, garnet-amphibolites, and hornblende-pyroxene-granulites. These materials are surrounded by grey acid biotite-gneiss, which here plays the same part as the pyroxene-gneiss with blue quartz to the older basic masses in the Lochinver area. With the development of large felspars the acid portion passes into coarse augen-biotite-gneiss, and, in places, it becomes so massive that it merges into granite.

The igneous origin of these members of the complex is strengthened by the great abundance of knots and lenticles of basic material in the acid gneiss. These inclusions consist mainly of rudely-foliated hornblende-rock and occasionally of a dark gneiss rich in biotite, the latter differing in character from the gneiss of the region. Their relations to the acid gneiss suggest that they represent inclusions in an igneous magma. The various stages can be traced showing the differentiation of the acid and basic materials, the gradual appearance of foliation in the acid portion, and the development of parallel banding in the acid and basic constituents. These phenomena are satisfactorily explained by Teall in his discussion of the architectural features of the Fundamental Complex:

'After a complex of this kind had been formed, either by differentiation, or by the intrusion of more acid into more basic materials, or to both of these operations combined, the secondary and more striking features were undoubtedly determined by plastic deformation.'[1]

In the Loch Maree and Gairloch[2] area the prevalent type of rock in the complex is an acid gneiss with biotite and some muscovite; the felspars present are oligoclase, microcline, and occasionally orthoclase. It often contains felspar 'eyes', composed in some instances of microcline or microperthite. Quartz, generally semi-opalescent, is abundant. The structure is granitic, except in those zones that have been sheared by movements since the intrusion of the dykes, where it is granulitic. The early banding of the acid gneiss sometimes displays a wavy structure, traversed by planes oblique to the folia, like the pyroxene-gneiss of the Lochinver area. This feature may have been produced by movement preceding the consolidation of the rock.

The acid gneiss in the Loch Maree and Gairloch area surrounds the ultrabasic rocks (hornblendites, peridotites), which have small dimensions, and also the early basic materials and hornblende-gneiss that together form a considerable part of the complex. Many of the early basic rocks are massive and show only occasional foliation. One of their distinctive features is the intimate association of extremely acid with highly basic parts, which suggests that the mixing and banding of the materials were developed when they were still in a viscous condition. By means of this intermixture the early basic rocks can be readily distinguished in the field from the later basic dykes. In a narrow belt west of Poolewe, extending from Naast on the shore of Loch Ewe south-eastwards by Creag Mhòr Thollie to the outlet of Loch Maree, two types of hornblende-gneiss occur, the first characterized by compact hornblende and a granular structure, the second by hornblende in fibrous or other aggregates. In the former case the hornblende is supposed by Teall to be original, but in the latter it is regarded as derived from an earlier pyroxene. South-westwards across the Tollie area where the gneiss and dykes are largely deformed, and across the Gairloch syncline of sedimentary schists, the acid gneiss and early basic rocks are not much altered.

Farther south, in the northern part of the Loch Torridon area, the

[1] 'The Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), p. 71.

[2] Gairloch = the short loch.

original type consists of a massive, quartzose pyroxene- or hornblende-gneiss in which the early banding is faintly marked. Southwards to the north shore of the loch this early banding is gradually replaced by the secondary foliation, the discordance between the older and newer foliation-planes being well marked. The modified gneiss is exposed on both sides of Loch Shieldaig, where it consists of a flaggy, well-foliated biotite-gneiss with a north-west strike. It is associated with bands of highly acid material, consisting chiefly of quartz and felspar, which are folded and incorporated with the gneiss. These have the appearance of foliated pegmatite, and may represent early acid intrusions in the original complex.

In Rona and Raasay the dominant type of rock in the Fundamental Complex is a biotite-gneiss containing microcline, which is associated occasionally with hornblende-gneisses. Definite parallel banding is not a marked feature in Rona, but in Raasay it is more persistent. In the latter tract the divisional planes often dip at gentle angles, the general strike being north-west and south-east. A medium-grained pink gneiss is of common occurrence in Raasay, some parts of it being rich in biotite, others in quartz and felspar. The more basic gneisses show a differentiation into quartzo-felspathic and dark hornblendic portions. Pink pegmatites, in which microcline is the dominant felspar, are associated with the pink gneisses and occasionally merge into the more acid portions of these rocks. White pegmatites, with oligoclase as the prominent, if not the only, felspar, occur in connexion with the more basic parts of the gneiss.

Bands of hornblende-schist, displaying clear transgressive junctions with the fundamental gneiss, have been traced both in Rona and Raasay, and to these reference will be made in the section dealing with the effects of the pre-Torridonian movements on the basic dykes (p. 41).

Later Basic and Ultrabasic Dykes. In the Gruinard area the gneiss complex is traversed by numerous basic and a few ultrabasic dykes, the latter being the earlier, thus reversing the order of intrusion of these igneous materials in the Lochinver region. The earlier series are soft, olive-grey, coarse-grained rocks that form prominent features in the landscape. They are of variable width, have clear intrusive junctions, and trend in a more westerly direction than the basic series which intersect them. They are unfoliated in the centre, but slightly schistose at the margins. The movements that produced this schistosity preceded the eruption of the basic dykes, thus indicating that the earth-stresses which developed the foliation must have been intermittent. There must have been alternate periods of tension and compression during the period of these later igneous intrusions.

The basic dykes in the northern part of the Gruinard area consist of massive epidiorites, showing clear intrusive junctions, except in narrow zones of shearing where they become schistose. In certain localities their north-west trend is nearly at right angles to the strike of the early banding of the original basic and ultrabasic masses. Southwards they gradually lose their massive character and appear partly or wholly as hornblende-schist, the foliation being parallel to their margins and to the prominent foliation in the gneiss.

Farther south in the Loch Maree and Gairloch area the development of schistosity in these later basic intrusions occurs in a more pronounced form. The great majority of them appear as hornblende-schists which have shared in the movements affecting the gneiss. Where the rocks are undeformed, however, the dykes are vertical and show intrusive junctions, as on the south-west shore of Loch Maree nearly opposite Ardlair, and south of the Gairloch syncline of sedimentary schists near Braigh Horrisdale. At the former locality traces of the original pyroxene have been observed in these intrusions. A specimen taken from the centre of one of them has been termed by Teall an 'ophitic dolerite'.

Similar evidence regarding the behaviour of the basic dykes is to be found in the Loch Torridon area, where to the north of Upper Diabaig they occur as coarse epidiorites crossing the banding of the original gneiss. Elsewhere in that region they appear as hornblende-schist.

Later Acid Intrusions. The latest phase of igneous intrusion in the Southern District is marked by the uprise of acid material, which, in the Loch Maree area, takes the form of pegmatites traversing the gneiss of the Fundamental Complex, the basic dykes, and, in some instances, the metamorphosed sediments. Their constituents are plagioclase, orthoclase, and microcline felspar with biotite, muscovite and quartz. They are to be seen near the centres of the Tollie and Carnmore anticlines, their general trend being towards the north-west. Many of them cross dykes of hornblende-schist though they themselves are unfoliated. Some examples, however, have been sheared by later movements. These phenomena are merely the counterpart of those already described in connexion with the Laxford area.

Similar evidence of the intrusion of later pegmatites is to be found in the Loch Torridon region. Some are parallel to, while others transgress, the foliation planes of the granulitic gneiss and hornblende-schist bands. Many of them are well foliated, and in some cases show large 'eyes' of microcline felspar.

In Raasay sill-like masses of pink granite crossing the banding of the biotite-gneiss were recorded by Teall, who suggested that much of the pink gneiss that has been mapped as part of the Fundamental Complex in that island may be of the same age as the gneissose granite of Laxford.

The Loch Maree Series of Sedimentary Origin. As already indicated, the prominent members of this series of crystalline schists are brown mica-schists, mica-schists with actinolite, graphite-schists, quartz-schists, and limestone (Pl. VII, 2). Clough called attention to the close resemblance of the altered sediments in the Letterewe basin to those in the Gairloch syncline, and suggested that they were probably once continuous. Peach inferred from the association of graphite-schist, limestone, and chert that the members of this series were formed at or near the extreme limit of sedimentation, where the graphite, the limestone, and the chert were probably accumulated from the remains of plankton.[1] But all traces of original organic structure have been destroyed by the metamorphic processes which they have undergone. No clastic grains have been detected in any of these rocks, and they differ in this respect from many of the members of the Moine Series lying to the east of the post-Cambrian displacements. But, notwithstanding this contrast, it is worthy of note that the brown mica-schist of the Gairloch and Letterewe synclines bears a close resemblance to the flaggy mica-schist in the Dalradian Series at Findlater Castle on the Banffshire coast west of Portsoy.[2]

The altered sediments are folded with sills of hornblende-schist, which occupy much larger areas at the surface than the sediments with which they are associated. They evidently represent what were originally intrusive igneous rocks, though no transgressive junction with the sedimentary schists has been recorded.

In the Letterewe basin the altered sediments form several narrow strips trending north-west and south-east, which, together with the sills of hornblende-schist, are thrown into a complex syncline as shown in the left half of the lower section of Fig. 3. Clough suggests that the rocks may have been folded before the development of the Letterewe syncline. The Furnace band—the broadest of the series—extends along the shore of Loch Maree for a distance of five miles from Letterewe. But near Smiorasair and Ardlair the basin is bounded on the south-west side by a pre-Torridonian fault, which brings the sedimentary schists against the deformed fundamental gneisses and basic dykes. Along the north-east margin of the basin the nature of the boundary is obscure, for, although the altered sedi-

[1] *Rep. Brit. Assoc. for 1912*, Dundee meeting, p. 448.
[2] 'The Geology of the Fannich Mountains and the Country around Upper Loch Maree and Strath Broom', *Mem. Geol. Surv.* (1913), p. 30.

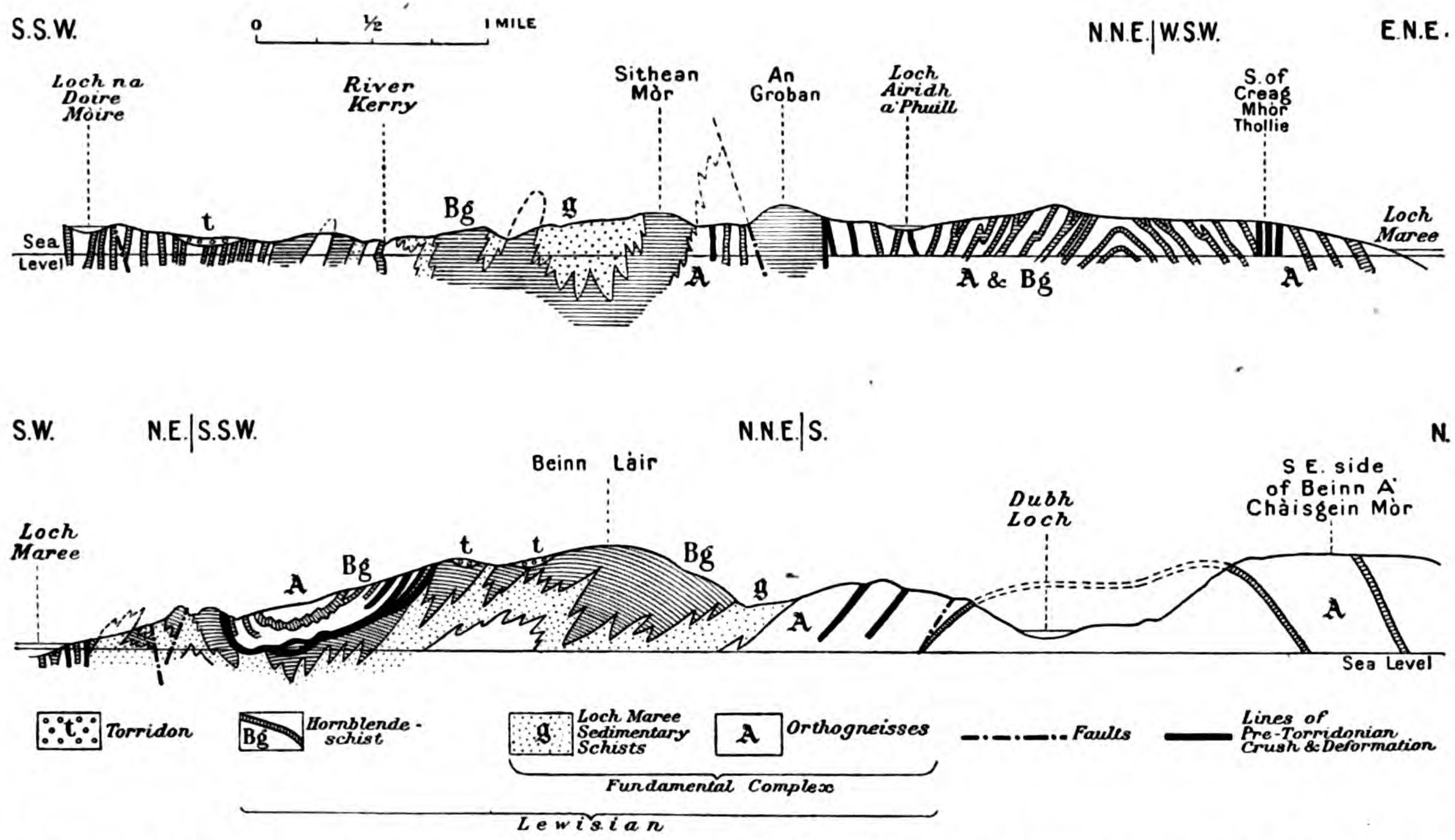


FIG. 3. Sections across Lewisian, Loch Maree. The upper section crosses Fig. 4. The lower section lies to E. of Fig. 4 in Sheet 92, *Geol. Surv. One-inch Map Scot.* See also Fig. 5. In choosing the two lines of section allowance has been made for horizontal displacement along the Loch Maree wrench-fault. (*Based on C. T. Clough in 'N.W. Highland Memoir', Pl. XXX.*)

ments dip steeply away from the gneisses of the Fundamental Complex, Clough was of opinion that the junction line there might probably be a thrust-plane.

A feature of special interest is the occurrence of an isolated slice of deformed Lewisian Gneiss and dykes resting upon the Loch Maree Series and associated hornblende-schists in the centre of the Letterewe syncline (between Loch Maree and Beinn Làir, Fig. 3). Attention will be directed to this remarkable feature in the section dealing with pre-Torridonian movements (p. 42).

In Gairloch (upper section of Fig. 3) the main belt of altered sediments with the accompanying hornblende- and chlorite-schists extends for about eight miles in a north-west and south-east direction, but the synclinal arrangement is not so apparent as at Letterewe. The original relation of the Loch Maree Series to the Fundamental Complex is no less obscure; for the north-east and south-west margins of the main belt are bounded by disruption lines, characterized by bands of flinty crush-rock (mylonites) separating the altered sediments and hornblende-schists from the deformed gneiss and dykes of the complex. Beyond the main belt in a south-west direction narrow strips of sedimentary schist, accompanied by flinty crush-rock (mylonite), are interleaved in fundamental gneisses.

Additional evidence of the isolated occurrence of lenticular strips of rock of sedimentary origin in the complex of gneiss and dykes is to be seen near Carnmore, about a mile and a half north-east of the Letterewe syncline, where three narrow bands of kyanite-gneiss have been traced for short distances in massive gneiss. One of them, from sixteen to thirty feet broad, is well defined, but thrust-like lines appear in the contiguous rock, thus suggesting that the kyanite-gneiss in this particular band occurs along a line of movement.

From the evidence above described it is obvious that no definite conclusion can be reached regarding the original relation of the Loch Maree Series to the Fundamental Complex. Gunn, who mapped part of the area occupied by these rocks, held the view, shared by Peach, that the sedimentary schists formed a newer series, unconformable to the rocks of the complex, and that a long period elapsed during which the fundamental gneisses and dykes were denuded before the sediments were laid down upon them. The unconformable junction had been effaced by the shearing movements which had affected both series in common. He called attention to the fact that no member of the Fundamental Complex and no dyke traversing that complex had been found to pierce any of the altered sediments or the associated sills of hornblende-schist.

Clough, on the other hand, was of opinion that the sedimentary schists might be older than the gneisses of the Fundamental Complex, and that the basic dykes rising through the complex might have acted as feeders of the hornblende-schist sills accompanying the altered sediments. He was impressed by the fact that the kyanite-gneisses near Carnmore and the limestone near the outlet of Loch Bad an Sgalaidh, close to the Gairloch syncline, occur within massive gneisses, and seem to pass gradually into them. He suggested 'that many of these massive gneisses may be paragneisses—gneisses of sedimentary origin—there being much more sedimentary material in the Lewisian Gneiss than our present knowledge enables us to differentiate'.[1]

Pre-Torridonian Movements. The Southern District furnishes numerous examples of the production of granulitic gneiss from the original gneisses of the complex and of the alteration of basic dykes into hornblende-schist by later movements. The general direction of these movements is north-west, that is, more or less parallel to the trend of the basic dykes, but a few instances of the east and west disruption lines have also been recorded. One of the latter, east of the Gruinard River, crosses several dykes which have been deflected, attenuated, and changed into hornblende-schist as in the tract between Kylesku and Scourie.

In the Loch Torridon area and also in Rona and Raasay, as previously indicated, bands of hornblende-schist with transgressive junctions appear to represent the dykes. In the Sheildaig region south of Loch Torridon the intrusive junctions have been so destroyed by later movements that the hornblende-schist bands now appear to form an integral part of the reconstructed gneiss.

The most striking feature connected with the later movements in the Loch Maree region is the development of broad folds in the fundamental gneiss, basic dykes, and the sedimentary schists, after the shearing of some of the dykes and the crumpling and shearing of the gneisses of the complex. In addition to the Letterewe and Gairloch synclines containing the belts of altered sediments, to which reference has already been made, the structural features of the Tollie arch between Loch Maree and Gairloch are of special importance. This area was mapped in great detail by Clough, the results of whose work, which are summarized below, throw light on the development of linear foliation and plane-parallel foliation alike in dykes and gneiss.

South of Poolewe the members of the Fundamental Complex and later basic dykes are thrown into a broad arch, the axis of which runs north-west and south-east, as is well shown on the map (Fig. 4, based

[1] Ibid., p. 16.

on One-inch Geological Map of Scotland, Sheet 91). Before this anticlinal arrangement was developed the dykes and gneiss had been plicated on more or less highly inclined vertical axes, the dykes being rendered schistose in part. The later system of folding, however, produced a complete rearrangement of the constituents both in dykes and gneiss. The latter rock consists there of augen-biotite-gneiss, with ultrabasic and basic masses, traversed by basic dykes which show types of foliation that differ according as they have been developed on the crest or limbs of the arch. In the former case, where the dykes are nearly flat and still show intrusive junctions as they curve round the end of the anticline, linear foliation or 'rodding' is developed, which is parallel with the pitch of the flexures. In the limbs of the fold, on the other hand, plane-parallel foliation appears alike in the dykes and gneiss, the planes common to both rocks dipping away from the anticlinal axis, that is, to the north-east and south-west. It would thus appear that differential movement of the constituents may be superinduced by folding which may lead to partial or complete reconstruction of the dykes and gneiss, and to the development in them of common planes of schistosity.

The granulitic gneisses and hornblende-schist of the Tollie arch are bounded on both sides by disruption lines, accompanied by mylonites, which on the north-east limb separate them from the hornblende-gneiss and dykes of the Fundamental Complex, and, on the south-west limb, from the broad band of hornblende-schist associated with the altered sediments of the Gairloch syncline (Fig. 4).

Another notable feature of the later pre-Torridonian movements is the occurrence of a narrow belt of Lewisian Gneiss and dykes in the centre of the Letterewe syncline (left part of lower section, Fig. 3). It stretches for a distance of four miles between Folais Burn and Ben Slioch; it tapers out north-west of Letterewe, and, towards the south-east, is covered unconformably by the Torridon Sandstone. The south-eastern prolongation of this belt appears as a pre-Torridonian hill at Meall Riabhach near the head of Loch Maree. The rocks consist of acid augen-biotite-gneiss with basic masses, traversed by basic dykes in the form of hornblende-schist. The structure of the gneiss is mainly granitic, but granulitic types occur. This belt rests upon the altered sediments and the associated hornblende-schists and is separated from them by a folded zone of mylonized rocks. Hence it might reasonably be inferred that the superposition of the gneiss on the sediments might here be due to overfolding and thrusting. But as the synclinal arrangement of the rock masses is later than the development of most of the mylonites in the folded zone, Clough was inclined to doubt this

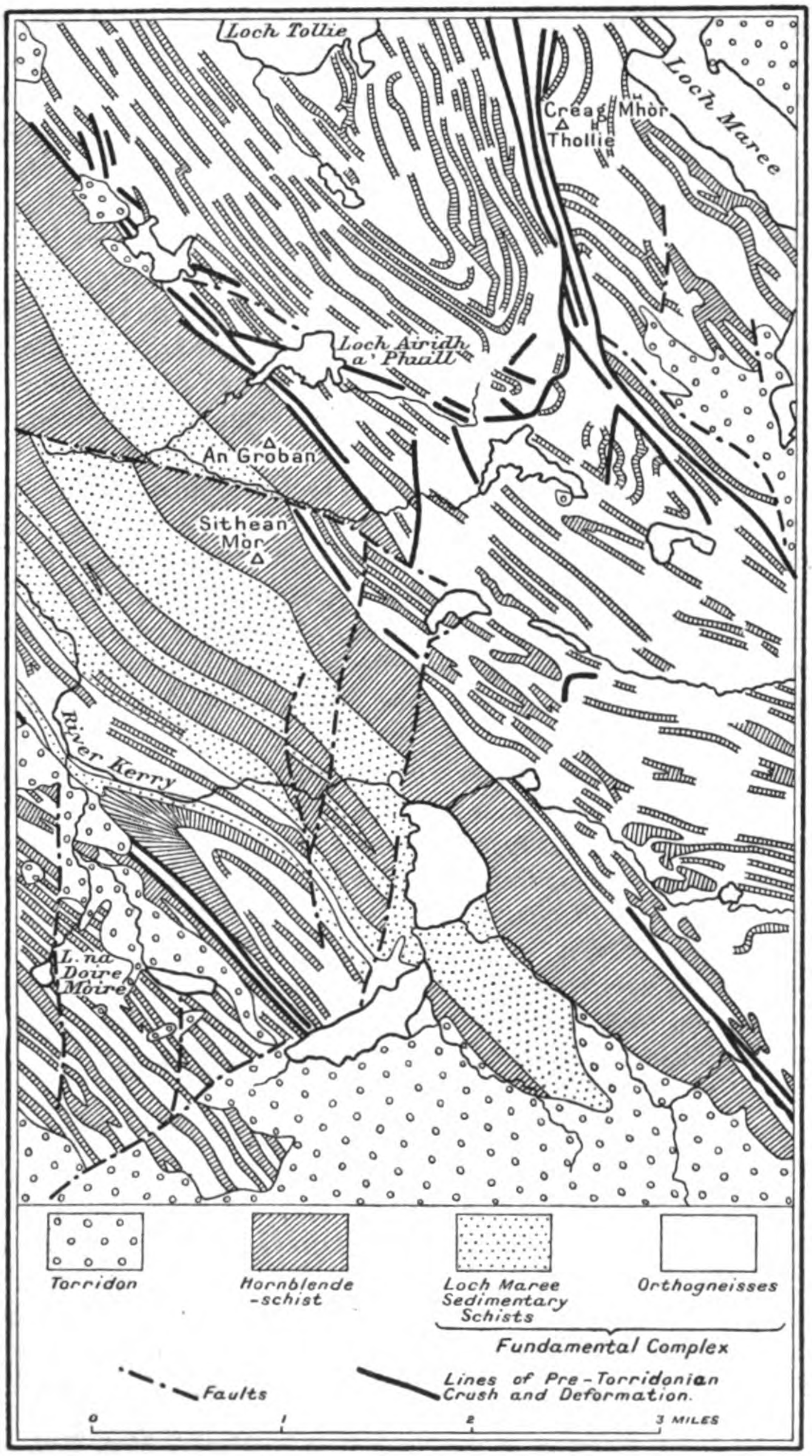


FIG. 4. Map of anticline in Lewisian Gneiss and Dykes, at Loch Tollie, west foot of Loch Maree (see Figs. 3 and 5). (*Based on C. T. Clough in Sheet* 91, *Geol. Surv. One-inch Map Scot.*)

interpretation of the geological structure. He contended that we had no definite knowledge how the mylonites were inclined before the syncline was formed. They might have been nearly vertical. Peach, on the other hand, suggested the hypothesis that the granulitic gneisses and hornblende-schist dykes forming the Tollie arch and those in the Letterewe syncline resting on the sediments are portions of the same displaced mass, isolated by denudation, and brought forward by a thrust probably from the south-west (Fig. 5).

The development of mylonites or flinty crush-rocks, to which reference has already been made, is another characteristic of the later pre-Torridonian movements in the Loch Maree area. Those may arise from the deformation of the basic members of the complex, the acid gneiss, pegmatites, and the hornblende-schist of the basic dykes. Some of them are older than the development of the broad anticlines and synclines, others are later than these flexures. Those formed from the acid gneiss weather with a white crust, but are dark-brown or black in fresh fracture; others representing the basic rocks have a dark-brown or black surface. Under the microscope they show clear indication of crushing; the acid streaks display augen of felspar and the basic streaks eyes of hornblende, surrounded by cryptocrystalline material.

Near the mylonized zones curious dark-brown, grey, or black strings, rarely more than an inch thick, traverse the rocks, and, in their behaviour, simulate small igneous intrusions. When examined microscopically signs of fluxion appear in the microlitic ground mass, and the fragments of quartz and felspar show cataclastic structures. Clough suggested that 'by the intensity of crushing near them sufficient heat may have been generated to fuse small portions of the rock'.[1] He compared them to the *trap-shotten* gneiss as described by Sir Thomas Holland from the Charnockite Series of India.[2]

Lewisian Gneiss affected by Post-Cambrian Movements

The results of the detailed mapping of the Lewisian Gneiss by the Geological Survey along the western seaboard of Sutherland and Ross, which have been described in the previous sections, prove that the Northern, Central, and Southern Districts of this belt are characterized by distinctive rock-types. These reveal a long complicated history of successive intrusions of igneous materials which still show the original banding over wide areas. They prove the

[1] 'The Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), p. 280.

[2] 'The Charnockite Series', *Mem. Geol. Surv. India*, vol. xxviii, part 2 (1900), pp. 198–202.

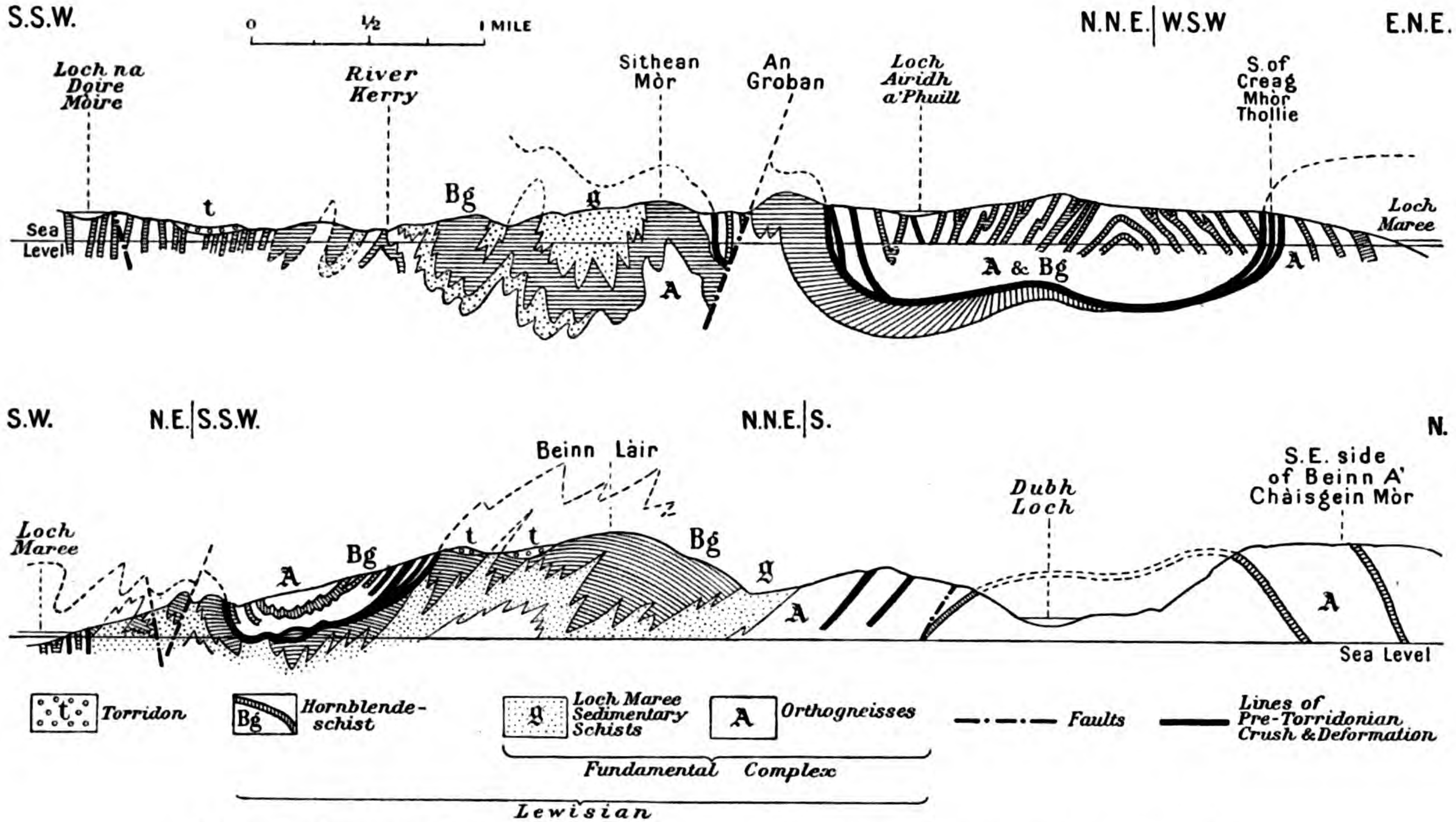


FIG. 5. Sections across Lewisian, Loch Maree. Suggested interpretation of Fig. 3 by B. N. Peach.

uprise at a later stage of dykes, sills, and irregular veins of ultrabasic, basic, and acid rocks; the occurrence, in certain localities, of schists of sedimentary origin associated with massive gneisses; and a great intermittent series of pre-Torridonian movements that developed new structures alike in the gneiss, dykes, and later acid intrusions.

We shall now proceed to show that the displaced masses lying to the west of the Moine Thrust, between the north coast of Sutherland and Skye, contain types of Lewisian Gneiss which resemble, and are often identical with, some of those that occur in the three districts in the undisturbed pre-Torridonian belt to the west.

It can be demonstrated also that some of these thrust masses of Lewisian Gneiss are overlain unconformably by Torridon Sandstone, and Cambrian strata, including the *Olenellus* zone. It is obvious, therefore, that these post-Cambrian disruption lines must have intersected the old Archaean floor on which the Torridonian and Cambrian strata were deposited.

Several displaced masses on the east side of Loch Eireboll, on the north coast of Sutherland, contain rocks of Cape Wrath type. They appear at Whitten Head (Ceann Geal Mòr), on Beinn Poll Ath-roinn (now known as Ben Arnaboll), and at Creag na Faolinn, where they consist of hornblende-gneiss and biotite-gneiss, traversed by veins of granite and pegmatite. The rocks are not much deformed except near the thrust-planes. At all these localities the basal Cambrian quartzites are to be seen resting unconformably on the gneiss, sometimes infolded on the western face of the displaced mass, sometimes inverted beneath it, sometimes forming an isolated patch on its denuded surface.

In the Glencoul thrust mass of Lewisian Gneiss, which has been traced continuously for six miles from Beinn Bhùtha, south of Loch More to the northern slope of Glas Bheinn in Assynt, valuable evidence is obtained. The types of gneiss in this mass at the head of Loch Glencoul do not resemble the pyroxene-gneiss with basic dykes in the undisturbed area immediately to the west. They consist of hornblende-gneiss with broad veins of red pegmatite and granite resembling the types near Loch Stack at the north-east margin of the Central District. It is worthy of note, also, that the basic dykes begin to appear in the thrust gneiss near the head of Loch Glencoul, just as they do one mile south of Laxford in the unmoved area. Still farther south on the northern slope of Glas Bheinn pyroxene- and hornblende-gneisses with basic dykes are exposed in the displaced mass, which resemble the rocks near Scourie. It thus appears that definite petrological types of Lewisian Gneiss, occurring in the unmoved area west of the belt of complication, are to be seen several miles to the south in the Glencoul Mass, carried westwards by the post-Cambrian movements.

No less important is the evidence proving that this slice of Lewisian Gneiss, reaching a maximum thickness of 1,000 feet, is really a portion of the old Archaean floor, for at its northern and southern margins it is overlain unconformably by the Cambrian quartzites and the *Olenellus* zone.

The materials driven westwards by the Ben More Thrust furnish confirmatory evidence. The great mass of Lewisian Gneiss, exposed on the lofty cliffs around the Ben More corries and on Sgonnan Mòr, contains pyroxenites, hornblendites, grey pyroxene-gneiss, and hornblende-gneiss with blue quartz, in which the original structures can still be recognized. They are traversed by numerous basic dykes mostly of epidiorite, trending in a north-west direction, and some ultrabasic dykes of picrite. These rocks closely resemble the types that occur between Scourie and Kylesku and in the Lochinver region of the Central District.

In the Corrie Dubh Loch Mòr, south of Ben More, the Lewisian Gneiss is overlain unconformably by the Torridon Sandstone with its basal conglomerate, which is capped in turn by the Cambrian quartzites, resting partly on the Torridonian beds and partly on the gneiss and dykes, thus repeating the double unconformity of the quartzites, so clearly displayed in the undisturbed area to the west (p. 91). When the basal quartzites are followed eastwards towards the head-waters of the Cassley River they are succeeded by the various subdivisions of the pipe-rock, the *Olenellus* zone and the limestone (Geological Survey Assynt District Map, one inch to one mile).

Certain petrographical types characteristic of the unmoved Lewisian Gneiss in the Southern District have been recognized in the displaced masses west of the Moine Thrust in Ross-shire. A considerable area of the Fundamental Complex, measuring about twelve square miles, appears on the moor north of Kinlochewe above the Kinlochewe thrust-plane. It contains ultrabasic and early basic materials, the latter consisting of hornblende-gneisses and amphibolites, which are surrounded and invaded by coarse granitoid gneiss or gneissose granite, merging in places into granite with no banding. Numerous dykes of epidiorite with vertical junctions and some ultrabasic dykes intersect the gneiss. These rocks recall the types in the Gruinard area in the northern portion of the Southern District. This mass of displaced gneiss is also covered unconformably by the Torridon Sandstone and shows the double unconformity between the Cambrian strata and the Torridonian and Lewisian rocks.

Still farther south, in the Loch Carron area, additional evidence is furnished by the displaced materials above the Kishorn thrust-plane. The old floor of Lewisian Gneiss is there overturned and lies at a gentle angle on the inverted, basal, epidotic grits, black shales, and sandstones, belonging to the lowest division of the Torridon Sandstone. This great inversion has been traced for several miles to the north and south of Loch Carron, where it forms a striking feature in the topography. It is important to note that, north of Loch Carron, this slice of Lewisian Gneiss contains a thick sill of epidiorite and hornblende-schist, associated with mica-schists, and rusty brown, slightly graphitic schists, recalling the altered sediments that appear in the Loch Maree district in the undisturbed area of Gneiss.

The above examples taken at intervals along the belt of complication from the north coast of Sutherland to Loch Alsh—a distance of ninety-five miles—prove beyond doubt that slices of the ancient platform of Lewisian Gneiss with the Torridonian and Cambrian rocks, including the Olenellus *zone, were driven westwards by the great post-Cambrian displacements west of the Moine Thrust.*

OUTER HEBRIDES

i. *Lewis (Northern Part of the Outer Hebrides).*

After our retirement from the Geological Survey we visited North Lewis in 1911 with the view of comparing the Archaean rocks, previously described by Macculloch,[1] Murchison,[2] Heddle,[3] James Geikie,[4] and others, with the types of Lewisian Gneiss on the western seaboard of Sutherland and Ross. Owing to the widespread covering of peat the sections examined were confined mainly to the coast-line. They were taken at intervals along the east coast between Tolsta Head, north of Stornoway and Loch Bhrollum, opposite the Shiant Isles[5]; and along the west side between the Butt of Lewis and Carloway. Traverses were made across the island (1) from Barvas on the west to Stornoway, thence across the Eye Peninsula to Tiumpan Head; (2) from Carloway south-eastwards by Callernish to Keose on Loch Erisort, about eight miles south of Stornoway. Our observations were not based on detailed mapping of any part of North Lewis.

Specimens with descriptive notes were submitted to Sir J. S. Flett for examination, who supplied a valuable report (pp. 52–9).

[1] *A Description of the Western Islands of Scotland* (1819), vol. i, p. 171.

[2] 'The Altered Rocks of the Western Isles of Scotland and the North-Western and Central Highlands', *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 172.

[3] In *A Vertebrate Fauna of the Outer Hebrides*, by J. A. Harvie-Brown and T. E. Buckley, 1888.

[4] 'The Glacial Phenomena of the Long Island or Outer Hebrides', *Quart. Jour. Geol. Soc.*, vol. xxix (1873), p. 534; xxxiv (1878), p. 820.

[5] Gaelic, *Na h-Eileanan Sianta*, the hallowed isles.

In the areas examined there is a marked absence of the massive quartz-pyroxene-gneiss with later basic and ultrabasic dykes, so characteristic of the tract between Scourie and Lochinver. The main components of the complex consist of biotite-gneiss, biotite-hornblende-gneiss, and hornblende-gneiss, resembling types in the Cape Wrath district, with a small development of later acid intrusions. No rocks of sedimentary origin, corresponding to the Loch Maree Series of the mainland, were recorded. A feature of special interest is the occurrence of flaggy granulitic gneisses, which, in the field, bear a close resemblance to the granulites of the Moine Series in the counties of Sutherland and Ross. Further, there is conclusive evidence that the members of the complex were extensively affected by subsequent movements, resulting in the development of platy rocks, noted by Macculloch, and of mylonites and flinty crush-rocks along definite lines of shearing.

Distribution of the Lewisian Gneiss in North Lewis

The muscovite-biotite-gneisses and biotite-gneisses are exposed on the shore at the Butt of Lewis near the Lighthouse, where their resemblance to certain granulites of the Moine Series arrested our attention. They are flaggy granulitic rocks, containing quartz, felspar, biotite, some muscovite, and occasional grains of hornblende. Their strike is nearly north and south, and they are overfolded on axial planes that dip towards the east at comparatively high angles. In structure, jointing, and mode of weathering they simulate certain Moine gneisses in the north of Sutherland. When followed eastwards along the shore of Port a' Sloth similar types occur, but the angle of dip decreases. They are interbanded with granulitic hornblende-biotite-gneiss, both having common foliation planes. At Port of Ness harbour, two miles south-east of the Lighthouse, they are succeeded by normal biotite-hornblende-gneiss with basic bands of hornblende-felspar-rock. Whatever may be their origin these Moine-like types are evidently integral members of the Archaean rocks of North Lewis.

Gneisses of petrographical character resembling the granulites at the Butt of Lewis occur three miles north of Stornoway, in a quarry on the north side of the road leading to Barvas, near the stream Amhainn a' Ghlinne Dhuibh.[1] Here the strike of the schists is NNE. and the dip ESE. It is possible that these granulitic biotite-gneisses of Moine type may extend along the ridge of high ground between the Butt of Lewis and the Laxdale river, near Stornoway—a distance of about eighteen miles. Should this suggestion prove to be correct they would form an important feature in the Archaean rocks of North

[1] River of the black or dark glen.

Lewis. Flett's attention was specially directed to these types, and in his petrographical report (p. 59) he indicates wherein they resemble, and wherein they differ from, the members of the Moine Series in the counties of Sutherland and Ross.

Coarse-grained biotite-gneisses appear at several localities on the west coast, north of Barvas, where they are associated with basic bands of hornblende-gneiss. At Siorrabhig, about three miles north of Barvas, they are traversed by foliated granite, the foliation being parallel with that of the contiguous gneiss. These features recall familiar types in the Cape Wrath district of Sutherland, but in this part of the western seaboard of Lewis the strike is variable, ranging from nearly north and south to east and west.

Biotite-hornblende-gneisses are to be found near Stornoway (1) on the west side of the harbour, (2) in the stream traversing Stornoway Castle policies, (3) on the hill-top north-west of Stornoway Castle, where their strike is uniformly north-west. They contain basic bands of foliated hornblende-felspar-rock, and both have common foliation planes. Similar lithological types, rich in epidote, and with a persistent north-west strike, occur on the moor half a mile north of Barvas on the west side of the island.

Hornblende-gneiss is a prevalent type at Keose, on the north shore of Loch Erisort, on the east coast, where it forms knots, lenticles, and basic masses, associated with biotite-hornblende-gneiss, the strike being north-west and the dip south-east. The abundance of basic masses in the complex is apparent in the belt of ground stretching from Carloway south-eastwards by Callernish to Garynahine. These may represent early basic materials, but their field relations were not definitely ascertained. Additional evidence of the prevalence of types resembling those on the north side of Loch Erisort at Keose is to be found in the shore sections examined in the Eye Peninsula, (1) south of Tiumpan Head, (2) north of Garrabost, (3) south of Swordale. Basic knots and lenticles occur in hornblende-gneiss, associated with biotite-hornblende-gneiss and micaceous gneiss; the strike, with some exceptions, varying from north to north-east, and the dip from east to south-east.

An exposure of pyroxene-hornblende-gneiss with quartz was observed at Dalebeg[1] north of Carloway, where it is traversed by foliated granite. A band of altered ultrabasic rock occurs in the gneiss in the policies of Stornoway Castle, the relations of which were not determined. A band of hornblende-schist observed in the acid gneiss near Garrabost in the Eye Peninsula may represent a basic dyke.

Granite-gneisses with sheared and massive pegmatites have a

[1] Gaelic, *Dail Bheag*, little dale.

limited development. They were observed on the western seaboard between the Butt of Lewis and Carloway, on the north shore of Loch Erisort, in the Eye Peninsula, and in the coast section north of Tolsta Head. Sometimes the granite-gneisses and pegmatites intersect the other components of the complex and thus represent the later acid phase of intrusion; but in those cases where they are not transgressive it is difficult to distinguish the later granite-gneisses from the normal biotite-gneisses of the complex.

Microscopic sections of the foliated granite at Dalebeg near Carloway, noted by the early observers, are thus described by Flett:

'A muscovite-biotite-granite rich in microcline. The quartz is broken down to a granulitic mosaic. The felspars are microcline, perthite, orthoclase, and albite; they occur as irregular broken lumps surrounded by crushed quartz, muscovite, and epidote. Biotite is not abundant; there are in one slide a few crystals of deep-green chlorite; muscovite is plentiful and appears to be both primary, and a new development through alteration of felspar by movement. Epidote forms numerous small grains, and orthite is exceptionally frequent in large well-zoned crystals. Iron ores and apatite are rather scarce. Micropegmatite occasionally occurs. A type of granite rich in alkali, and with much silica, severely crushed so that it retains only few traces of its original igneous structures.'

The evidence of the production by later movements of mylonites, flinty crush-rocks, and, in some cases, of planes of disruption in the Archaean Complex of North Lewis is worthy of special reference. These phenomena were observed at several localities along the eastern seaboard between Tolsta Head, north of Stornoway and Camas Thomascro, WNW. of the Shiant Isles—a distance of about thirty miles. This type of mylonization closely resembles that associated with the Moine Thrust of post-Cambrian date. It is doubtless true that mylonites of pre-Torridonian age occur in the Lewisian Gneiss on the western seaboard of Sutherland and Ross, but they are usually accompanied or followed by the recrystallization of the original constituents of the rocks affected by the line of movement.

About a mile inland from Tolsta Head a belt of mylonized rocks is traceable from the hamlet southwards for two miles to Glen Dibidil,[1] the general strike varying from north to NNE. and the dip from east to ESE. Favourable exposures are to be found in Allt Dibidil and on the moor adjoining that stream. The gneiss there is sheared and a brecciated structure is developed. Fragments of hornblende and felspar lie in a fine-grained matrix, and, in a more advanced stage of crushing, the original constituents have been effaced.

The best sections of these phenomena in the area examined by us

[1] Better *Debidale*, deep dale (Norse).

occur on the south shore of Rudha Ranish, at Eilean Glas—a promontory about six miles south of Stornoway. Here a well-marked thrust-plane appears in the mylonized gneiss, inclined towards the east at an angle of 30°, overlain by platy, grey, pink, and striped mylonites with a similar dip. Ascending the sea cliff and following the outcrop of this line of movement northwards, we find the various stages in the formation of these mylonites from grey gneiss, basic bands, and pink pegmatite (see Flett's report, pp. 56–8).

Farther south at Camas Thomascro, the mechanical effects of crushing on the different members of the complex are clearly displayed. Hornblende-gneiss merges into green schist with an easterly dip, the hornblende being twisted and torn out into threads; the acid rocks pass into mylonites with phacoids of felspar and crushed quartz.

The evidence obtained at these widely separated localities points to the conclusion that the Archaean rocks along the eastern seaboard of Lewis were affected by lines of movement, running generally in a north and south direction,[1] which produced flinty crush-rocks and mylonites.

Report by Sir J. S. Flett, F.R.S., on the Archaean Rocks collected in the Isle of Lewis by Dr. Peach and Dr. Horne

In this collection the following classes of rocks are represented: (1) Muscovite-biotite-gneisses, (2) Biotite-gneisses, (3) Biotite-hornblende-gneisses, (4) Hornblende-gneisses, (5) Pyroxene-gneisses, (6) Hornblende-schist or Felspar-amphibolite, (7) Peridotite or Pyroxenite, (8) Sheared granite-gneiss, (9) Pegmatite-gneisses, (10) Mylonites.

1, 2. The muscovite-biotite-gneisses are few in number and are poor in muscovite. Hence they are hardly entitled to rank as a class distinct from the biotite-gneisses, which are well represented. The latter, especially those of the Butt of Lewis district, are the most characteristic types in the collection. They have, in hand specimens, a considerable resemblance to Moine granulites, being rich in quartz and felspar, which both occur as small rounded grains, while the biotite (the other principal component) tends to be scattered through the mass of the rock rather than segregated into definite folia. The plates of mica, however, have in the main a parallel orientation, so that the rocks are distinctly fissile though not so readily split along the foliation planes as typical muscovite-biotite-schists.

The rocks are typical granoblastic gneisses (granulites) without

[1] Dr. J. Wilson Dougal, who has devoted much time to the examination of the rocks in the Outer Hebrides, was the first to call attention to the occurrence of flinty crush-rocks in the Lewisian Gneiss of these islands.

porphyritic crystals, and without any remains of pebbles, or bedding, or of other clastic structures.

Where muscovite is present it occurs associated with the biotite, but it is never abundant and never occurs as the sole mica. In some of the rocks fine, scaly, white mica has been developed by crushing of the felspar.

The felspars are oligoclase, albite, orthoclase, and microcline; the last is distinctly scarce, but oligoclase is usually abundant, and, as it is often untwinned, care must be exercised in ascertaining its amount. Often the rocks are very felspathic.

Of the accessory minerals the most important are epidote, orthite, apatite, iron ores, zircon, and hornblende. Epidote is practically universal and orthite is almost never absent. The apatite sometimes occurs in large imperfect crystals, which are full of minute, tabular, fluid inclusions that give the mineral a grey colour. Iron ores and zircon on the whole are scarce. Sphene seldom occurs, but hornblende is often present, though sometimes only one or two grains occur in a micro-section; and this links the biotite-gneisses with the hornblende-gneisses.

Very few of these rocks evince no effects of stress. In the majority of them the quartz at least is strained and shows incipient granulitization; a further stage is represented by rocks in which the mineral grains are separated by thin seams of granulitic material, principally quartz. The felspar is much tougher than the quartz, and, at a certain stage, the felspar occurs as broken crystals with sub-rounded to elliptical outlines, enveloped in a mortar of broken-up quartz with some felspar. Strain-twinning then begins to develop in the oligoclase and albite, but the orthoclase is not changed. Mica and hornblende are both tough and difficult to fracture, but when they are caught in a mass of broken material they are twisted and torn out, so that the biotite crystals, for example, have frayed, broken-up ends, though the larger part of a crystal may be quite solid and compact. Similar changes are seen in the hornblende-gneisses and will be further described in that connexion. The ultimate stages of granulitization are represented by the mylonites (p. 56).

3. Biotite-hornblende-gneisses containing both hornblende and biotite are not numerous in the collection. Their biotite is deep-brown and strongly pleochroic, from pale-yellow to almost black in some rocks. The biotite is usually less abundant than hornblende, and certain folia or bands may contain only amphibole while others have biotite as almost the only ferro-magnesian component.

4. The hornblende-gneisses are evidently the dominant rocks in this collection. As a whole they are of rather fine grain, well-foliated,

and distinctly banded, uniform in texture, and thoroughly metamorphic in character. Their hornblende is of the green variety so common in hornblende-granites, with a pleochroism ranging from yellow-green to deep-green; occasionally bluish shades are seen on the margins of a crystal, but brown hornblende and very dark-green hornblende are not present. The principal felspar is oligoclase, and, as in the biotite-gneisses, it is often untwinned and consequently difficult to identify. Albite and orthoclase seem to be always present, and, sometimes, there is a little microcline. Micropegmatite of the vermicular kind (myrmekite) occurs in a few of these rocks as fringes to alkali-felspar but is never abundant. Of the accessories we may mention epidote, orthite, apatite (often grey in colour), sphene (rare), iron ores. Quartz varies a good deal in amount, some of these rocks being of rather 'acid' composition while others contain very little of it. As a whole the hornblende-gneisses are less felspathic than the biotite-gneisses.

The epidote and orthite are so important as to merit special description. They are practically never absent and often are present in abundance, so that they might be regarded as essential components of these rocks. The epidote is yellow (pistacite) and slightly pleochroic; colourless zoisite may also be seen but is distinctly rare. The orthite is in small grains, which may be of irregular shape or may show well-defined crystalline forms. It is always surrounded by broader or narrower rims of epidote, with which it is in parallel growth. Often the orthite is zoned, and it may be decomposed to yellow or brown products which have a very weak double refraction. Micropegmatite intergrowths of epidote and quartz are found in many of the rocks, but the structure has not been noted in orthite. The epidote occurs as granules seldom showing crystalline form and often associated in clusters with hornblende and biotite. It is never decomposed. Much of it seems to be as much of 'primary' origin as the hornblende, but zoisite and epidote may also arise from alteration of lime-bearing felspar, as will be described subsequently.

The hornblende-gneisses seem to be less readily granulitized by movements than the biotite-gneisses; still, effects of crushing can almost always be recognized in the rocks of this class, and they exhibit almost the same stages as the biotite-gneisses. The quartz breaks up before felspar and hornblende: consequently the least altered rocks show only strain shadows and occasional fractures in the quartz. The broken material seems to insinuate itself between the grains of felspar, so that a 'mortar' structure results. As this develops narrow seams of broken-up quartz and felspar separate broken phacoids of felspar and hornblende. Quartz never occurs as distinct phacoids as it is always granulitic before mortar structure is well developed. The hornblende does not granulitize though the ends of the crystals may be teased out into fibres.

In the hornblende-gneisses oligoclase is abundant and sometimes other felspars more rich in lime. Under granulitization epidote and zoisite are formed at the expense of the anorthite molecule, while the albite is set free. Consequently under the microscope many of the larger phacoids of felspar in these gneisses have a turbid or dirty appearance. Examination with high powers shows that they consist of a matrix of rather milky albite, often with good polysynthetic twinning, enclosing many little specks of epidote and small flat plates of white mica. We generally may observe that the mica occurs towards the interior of the crystal and its scales lie in all directions, but the epidote granules are commonest near the margins. The lime-soda-felspar has thus been converted into soda-felspar (albite), lime-alumina silicates (epidote and zoisite), and an alkali alumina silicate (white mica). The last-named may be derived from the orthoclase of which a small amount occurs dissolved in all lime-soda-felspars. The process has a close resemblance to a well-known type of saussuritization.

Now in the broken material which forms the cement or mortar between the grains of felspar, minute particles of epidote are constantly present. Their high refractive indexes make them conspicuous in spite of their small size, and they give a turbid dark appearance to the granulitic cement. Hence in ordinary light we may recognize in the microscopic slides thin layers of dark epidote granules separating the clear felspar crystals; they make a network with oval interstices in which the felspars lie. This epidotic web-structure is constantly seen in sections of the hornblendic gneisses of Lewis and gives the rocks a very distinctive character. Zoisite or epidote can also be traced as small rods spreading out from the epidotic web into the substance of the larger felspar grains.

The final stages of crushing will be described under the mylonites (pp. 56–8).

5. Only one slide of hornblendic gneiss containing a few, clear, pale-green crystals of pyroxene intergrown with amphibole, is present in this collection. It differs in no important respect from the hornblende-gneisses except in this respect. The rock contains quartz and is of distinctly acid character. There is no reason to suspect it is of sedimentary origin.

6. One or two dark-green, basic rocks may be described as hornblende-schists or felspar-amphibolite. They consist almost wholly of hornblende and felspar; the former, deep-green and strongly pleochroic; the latter, clear, polysynthetic, and belonging to the labra-

dorite-andesine group. In these rocks quartz may occur but only in negligible quantity. Iron oxides are practically absent, but apatite is visible in the slides. Effects of crushing are absent or very inconspicuous, which can only be due to the superior toughness of the rocks of this type as compared with the gneisses in which the easily fractured quartz is well represented.

7. The ultrabasic rock of Stornoway Castle grounds is in many respects very interesting, but its original nature is by no means easily determined. In its present condition the rock consists of a matrix of granular green hornblende, which in all probability is entirely of metamorphic origin and derived mainly from original pyroxene. It is not distinctly schistose. In this matrix lie phenocrysts (relict structures) which are entirely altered either by decomposition or by metamorphism. Some of them consist mainly of fine, scaly talc with some chlorite. These may represent primary enstatite or olivine; in fact some of them resemble olivine in outline, while others seem to have the cross-section of pyroxene crystals. There are also pseudomorphs of a brown, pleochroic, micaceous mineral which may be iddingsite or secondary mica, such as occurs in the scyelites. It is clear in any case that this rock is a metamorphosed ultrabasic igneous mass. Quite probably it has some connexion with the peridotite dykes that intersect the Lewisian Gneiss of Sutherland. It is of interest also as a type of alteration-product which has not hitherto been recognized among rocks of this group in Scotland.

8. Sheared Granite-Gneiss. This rock belongs to the group of muscovite-biotite-granites, and is rich in alkali felspar (microcline, microperthite, and orthoclase). It is much crushed, and the felspar crystals appear as broken lumps in a granulitic matrix. Epidote is present and orthite is exceptionally common in this rock. No other Scottish granite resembles it closely in composition and metamorphic condition.

9. The pegmatite-gneisses that intersect the other rocks of Lewis hardly merit a special description. They consist of alkali felspar (microcline, perthite, orthoclase, and albite) with quartz and a little oligoclase, muscovite, biotite, zircon, and apatite. In all cases they show crushing, but owing to their coarse grain and irregular structure they are seldom schistose. The mineral changes are the same as in the acid gneisses (1 and 2). Both epidote and orthite are visible in the crushed pegmatites.

The collection includes also some granulitized quartz veins.

10. The mylonites include the extreme stages of crushing of the other rocks. They have all a thin platy structure often with larger or smaller uncrushed grains appearing as elliptical phacoids. The acid

gneisses when mylonized are white, pink, or grey, but the hornblende-gneisses are pale or dark-green, fine-grained rocks with small dark fibres of hornblende on their splitting faces. Some of the mylonites have bands coloured bright-yellow by abundant epidote.

In the acid rocks the fine mylonite material is principally quartz, though it is usually mixed with a small amount of untwinned alkali felspar, easily recognized by its lower refractive index. The felspar often occurs as phacoids, but the quartz is always broken down before the rock can be recognized as a mylonite. Both quartz and felspar occur as small lenticular particles with elongation in the direction of the foliation and interlocking at their margins. The amount of white mica in the granulitic material varies greatly, but it is often abundant and takes the form of minute scales with strongly-marked parallel orientation. There is usually also much granular epidote which is often restricted to certain folia or narrow bands that give the sections a striped appearance. These folia are gently undulating but not strictly parallel. They enclose lenticular patches of quartz and felspar, and in this structure we probably have the consequences of the dragging out of the epidotic web so common in the granulitic gneisses. The felspar phacoids are always albite or alkali felspar; where basic felspars were originally present they have been transformed into epidote, sericite, and albite.

A little granular sphene, iron oxides, apatite, and zircon are not infrequent in the mylonites.

The hornblende, which is the only other mineral, takes a variety of forms. It seems to be distinctly difficult to break down, as fairly large grains of amphibole may be seen in rocks of which all the other minerals have been completely crushed. The hornblende phacoids do not differ in appearance from the hornblende in the massive rocks.

The last stages of crushing are represented by greenish platy mylonites in which nearly all the hornblende is reduced to fine fibres of pale-green colour, mingled with grains of epidote, flakes of sericite, and an almost cryptocrystalline aggregate of quartz and felspar.

Some of the mylonites have a brecciated appearance with lumps of quartz and felspar in a broken matrix, and grains of coarser mylonite surrounded or cut across by strings of finer material. Probably in such cases the movements were not uniform either in direction or in amount. Between these ultimate stages of mylonization and the unsheared rocks practically every transition can be found. The minerals break up in the following order, first quartz, then felspar, next hornblende: the quartzose bands are sometimes much more crushed than the others. From the alkali felspar sericite develops, though not always, and the exact conditions which determine this change are not easy to specify. From lime-bearing felspar epidote always is produced, accompanied by alkali felspar (albite). Hornblende persists in the last stages of crushing, though sometimes it would appear that chlorite is developed at its expense. Biotite is never produced. Sphene arises from the iron oxides, but apatite and zircon undergo no change.

The stages of mylonization may conveniently be grouped into three classes:

1. Mortar structure with thin bands mostly of crushed quartz enveloping the grains of the gneiss.

2. Flaser structure with abundant phacoids of felspar and hornblende in a granulitic matrix which shows foliation.

3. Mylonites in which the fine, drawn-out, crushed material is the principal component of the rocks, and the phacoids, though they may be numerous, are less important than the matrix.

The close affinities of the gneisses of the Lewis to those of Western Sutherland and Ross are sufficiently clear from the following considerations:

1. The abundance of hornblende-gneisses and biotite-hornblende-gneisses.

2. The pyroxene-gneisses are very typical Lewisian rocks.

3. The amphibolites belong to distinct Lewisian types like those of Cape Wrath district.

4. All the metamorphic rocks can be paralleled in the Lewisian Gneisses of West Sutherland and in no other British formation.

The rocks of North Lewis, however, present a facies which is not exactly similar to that of any other district in Scotland. Their chief peculiarities are:

1. The range of types is not so great as usual; hornblende-gneisses greatly preponderate; pyroxene-gneisses are few. There are no eclogites, pyroxene-granulites, &c.; and few peridotites or epidiorite dykes are present. Basic rocks are scarce, and no rocks of sedimentary origin (graphite-schists, limestones, or quartzites) occur in this collection.

2. In the more acid gneisses (muscovite-biotite-gneisses, biotite-gneisses, and biotite-hornblende-gneisses) the structure is generally of the granulitic type. The mineral grains are rounded, not elongated, and the rocks though banded are not very fissile. This gives the rocks a superficial resemblance to the Moine gneisses.

3. There is an excessive prevalence of cataclastic structures not only in the mylonized rocks of the shear-zones but throughout the whole complex. Mortar structure characterizes almost all the more acid gneisses. Teall, it may be remarked, has correlated the granulitic texture in Lewisian gneisses with effects of interstitial movement.

4. Certain mineral peculiarities are very striking: (1) none of the rocks contain garnet, (2) epidote is very abundant, (3) orthite is more frequent than in any other British rocks; it must be regarded as primary.

If we compare these rocks with the Moine Series of the east of Sutherland and Ross we find that while there are certain points of resemblance the distinctions are important and far-reaching.

Some of the biotite-gneisses are very like Moine granulites both in the hand specimens and under the microscope. They have similar composition, consist of the same minerals, and have almost identical structures.

But in these biotite-gneisses, hornblende is often found in sporadic grains. Orthite is practically universal and often relatively abundant. Epidote is also exceedingly common. Mortar-structure is very prevalent. Not one of these features can be considered typical of the Moine gneisses.

The epidote-hornblende-gneisses are quite unlike any Moine rocks hitherto described. In the Moine Series zoisite-hornblende-gneisses of two types occur, but these are entirely different from the epidote-hornblende-gneisses of the Lewis.

The Moine amphibolites have strongly marked characters (e.g. they are often garnetiferous) which are quite different from those of the amphibolites of Lewis.

The absence of clastic structures, of quartzose granulites, of micaceous, muscovite-biotite-gneisses (psammitic and semipelitic gneisses), which are so abundant among the Moine rocks, is strong evidence that they belong to a different series.

ii. *The Barra Isles (Southern Part of the Outer Hebrides).*

The Archaean rocks in the Barra Isles are composed of various types of orthogneisses of igneous origin. The researches of Professor T. J. Jehu and Mr. R. M. Craig[1] have shown that they include basic hornblende-rock that appears to be the oldest member of the series, hornblende-gneiss, hornblende-biotite-gneiss, biotite-gneiss, and an acid muscovite-biotite-gneiss. The interbanding of the acid and basic members of the series is well displayed in certain localities. The general strike is NNW. and ESE., the dip of the foliation planes being ENE. No paragneisses of sedimentary origin have been observed.

These rocks are occasionally penetrated by bands of hornblende-granulite and pyroxene-granulite that show, in places, intrusive

[1] 'Geology of the Outer Hebrides. Part I.—The Barra Isles', *Trans. Roy. Soc. Edin.*, vol. liii, part ii (1923), p. 419.

junctions with the prevalent gneisses. Appearing as inclined sheets or dyke-like bands averaging a few feet in thickness, they usually run more or less parallel with the foliation of the contiguous gneiss. They possess a marked granulitic texture, are fine-grained, and sometimes merge into hornblende-schist. They are rarely traceable for more than a few hundred yards.

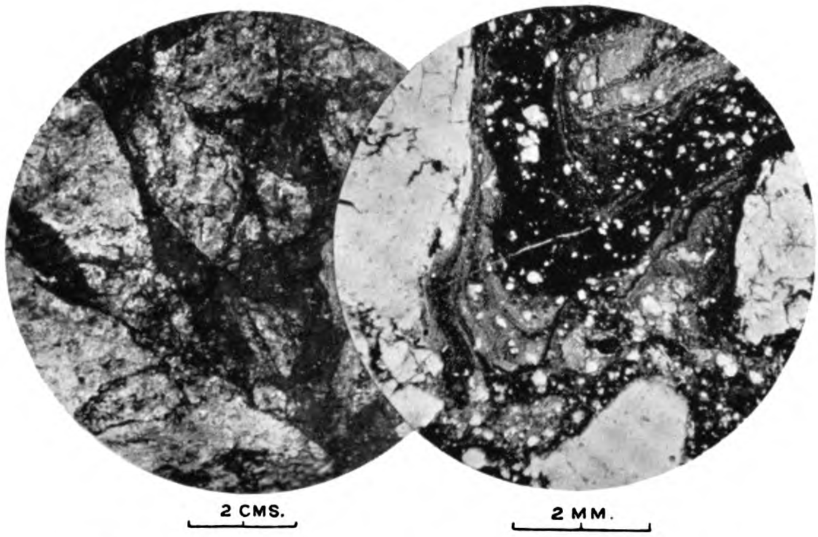
The orthogneisses and the dyke-like intrusions are cut by pink and grey pegmatites which are the latest members of the Archaean Complex. Their composition is variable; those traversing the biotite-gneiss and hornblende-granulites consist of albite-oligoclase, some microcline, quartz, dark-brown biotite, a colourless pyroxene, and a few grains of orthite. The pink varieties at Crubidale in the island of Fuday are composed mainly of microcline, some quartz, dark-green, much-altered biotite, with masses of magnetite up to the size of an egg.

A remarkable feature of the Archaean Complex in the Barra Isles is the development of the effects of dynamic metamorphism along certain definite lines. Professor Jehu and Mr. Craig have proved that the crush-zones show brecciation, granulitization, mylonization, and the formation of dark, flinty crush-rock on an extensive scale, especially among the hornblende-gneisses (Pl. VII, 1). All the types of gneiss and the pegmatites have been affected by these movements. A well-marked belt runs northwards across Sandray, Vatersay, and Barra, as far as Cuier, where it joins one trending east and west across Barra. Eastwards it occurs in the islets of Fuiay and Flodday, and bends towards the north-east in Hellisay and Gighay. It is suggested that these two belts may be one, the difference in trend being probably due to subsequent folding.

Near these lines of deformation the original foliation of the gneiss is dragged into parallelism with the trend of the crush-belt and is ultimately obscured or destroyed. All the stages in the fracture, shearing, and mylonization of the rock constituents are clearly displayed in the field. The dark flinty crush-rock sometimes occurs in a massive form when it resembles an intrusive basalt, sometimes as minute veins and strings penetrating the rock-mass either parallel to the direction of movement or more or less at right angles to it. These dark veins of pseudo-tachylite in places surround and isolate fragments of the gneiss, thus producing a peculiar pseudo-conglomeratic structure. These phenomena are well developed at Cuier in Barra, where they were observed by Macculloch, who naturally regarded these veins, whether great or small, as 'very compact, fine-grained, black basalt'.[1]

[1] *A Description of the Western Islands of Scotland* (1819), vol. i, p. 83.

PLATE VII



1. Flinty crush-rock in Lewisian Complex, Outer Hebrides (after T. J. Jehu and R. M. Craig).

2. Limestone in Lewisian Complex, Loch Maree.

The various stages of change from sheared gneiss into mylonite and dark, flinty crush-rock are more clearly defined under the microscope. In the prevalent types of gneiss the ferro-magnesian minerals are first affected; they supply the black magnetic dust and the brown colour of the fine-grained matrix. Wavy structure is developed. The quartz and felspar crystals are drawn out into lenticles and sometimes granulitized; the cracks traversing them are filled with black magnetic dust. Some microscopic sections show distinct spherulites, others radiating groups of felspar microlites, thus indicating incipient recrystallization.

From the evidence obtained in the Barra Isles, Professor Jehu and Mr. Craig have drawn the following important conclusion:

> 'The association of flinty-crush phenomena with belts of shearing and movement and the independence of the pseudo-tachylitic material of any connection with intrusive igneous rocks in the field, together with its behaviour as seen in hand specimens and in microscopic sections, leave no doubt in the mind of the observer that these peculiar rocks are the product of mechanical stresses which, at places, have raised the temperature to an extent sufficient to bring about partial fusion of the crushed gneisses.'[1]

iii. *South Uist and Eriskay.*

In continuation of their examination of the Lewisian Gneiss of the Outer Hebrides Professor Jehu and Mr. Craig[2] found that the rocks in these islands are composed mainly of gneisses and granulitic rocks, closely resembling those in the Barra Isles. The prevalent types are acid biotite-gneiss, hornblende-biotite-gneiss, hornblende-gneiss, and garnetiferous hornblende-gneiss. Pyroxene- and hornblende-granulites are sometimes met with, which, in places, are intrusive in the more prevalent types. Coarse acid gneisses and pegmatites, trending in various directions, penetrate the dominant members of the Archaean Complex. Pegmatites represent the last phase of igneous intrusion and seem to have followed closely on that of the later muscovite-biotite-gneiss. Felspar, usually microcline-perthite, is the most abundant constituent in the pegmatites, where it is associated with quartz and mica. An unusual type, consisting of quartz, white oligoclase, with crystals of hornblende, often edged and partly intergrown with biotite, was noted at the north-east corner of Oronsay.

Ultrabasic rocks (peridotites) occur at various localities usually in the form of bands but sometimes in a more irregular manner.

[1] 'Geology of the Outer Hebrides. Part I—the Barra Isles,' *Trans. Roy. Soc. Edin.*, vol. liii, part ii (1923), p. 436.

[2] 'Geology of the Outer Hebrides. Part II—South Uist and Eriskay', *Trans. Roy. Soc. Edin.*, vol. liii, part iii (1925), p. 615.

They are intrusive in the prevalent gneisses west of the sheared belt, and, though their age is uncertain, they are presumably members of the Archaean Complex, for the north-west end of the main outcrop in the island of Berneray is cut across by a pegmatite. No representatives of undoubted paragneisses were observed.

The general direction of strike of the foliation planes of the gneiss in South Uist is north-west and south-east or north-north-west and south-south-east, but in North Uist the trend is more variable. In the south-east of Benbecula the prevalent trend is north-west. Along the west coast of that island and North Uist it is frequently north-east and south-west, while at places in North Uist it is nearly east and west.

The remarkable feature of the Archaean Complex is the belt of sheared rocks and flinty crush-material, traceable at intervals along the eastern side of these islands. There can be no doubt that it is a continuation of the belt so prominently developed in the Barra Isles to the south. The base of the sheared gneisses in South Uist is defined by a zone of flinty crush-rock, striking north and south, and dipping towards the east at comparatively low angles. At some localities it reaches 100 feet in thickness. The behaviour of this zone in the field has led the authors to the conclusion that it overlies a thrust-plane along which the sheared rocks have been driven westwards. The thrust deformed gneisses are of the same general type as those to the west of the line of disruption, but there is no evidence as to the extent of the lateral displacement. In North Uist, however, the thrust-plane is well-marked and its outcrop is easily traceable.

The flinty crush-rock weathers with a black or brown surface, and has a pitchy lustre and splintery fracture. At some places it is difficult if not impossible to indicate the type of gneiss from which the flinty material has been produced; at others the various gradations from the deformed gneisses and pegmatites can be traced. The fine, crystalline ground-mass, when examined under the microscope, shows occasionally partial recrystallization of the fused material by the development of spherulites and microlites, as was found to be the case in the Barra Isles (p. 61).

In South Uist, to the east of Hecla, the broad band of crushed gneisses is followed eastwards by a narrow zone of mylonites, trending in a north and south direction. It is exposed on the shore of Usinish Bay and other localities.

An exceptional type of rock observed on the east coast of South Uist is described as a scapolite-bearing pyroxene-gneiss, which closely resembles a scapolite-pyroxenite from the Lewisian Gneiss at Badcall, near Scourie, Sutherland.

iv. *North Uist and Benbecula.*

The Archaean Complex of North Uist and Benbecula was found by Professor Jehu and Mr. Craig [1] to consist of gneisses and granulitic rocks for the most part, if not entirely, of igneous origin. The prevalent types are acid biotite-gneiss, hornblende-biotite-gneiss, hornblende-gneiss, and garnetiferous hornblende-gneiss. The more basic varieties sometimes contain pyroxene and pass into pyroxene-hornblende-granulites, which are frequently garnetiferous and intrusive in the other gneisses. Pink acid gneisses resembling pegmatites traverse the rocks on the west side of North Uist, and bands of pegmatite are of common occurrence throughout the islands.

Ultrabasic intrusions, usually in the form of bands, occur at several localities. The fresh material from Berneray shows, under the microscope, large plates of rhombic pyroxene, enclosing abundant olivine, often serpentinized, together with iron ores and a chloritic mineral apparently replacing biotite. Their age is uncertain, but they are probably members of the Archaean Complex.

Of special interest is the continuation northwards of the belt of crushed gneisses, mylonites, and flinty crush-rocks which occurs in South Uist. It was found on the east side of Benbecula and has been traced through the Isle of Ronay and along the eastern hills of North Uist to the south shore of Loch Maddy, thence north-eastwards along the high ground west of Loch Portan to the Sound of Harris. The base of this belt of deformed materials is defined by a well-marked thrust-plane, dipping towards the east, the outcrop of which follows the configuration of the ground. The belt in North Uist does not present such well-marked crush-zones as those farther south. All stages are displayed from mylonites through intermediate types to crushed and sheared gneisses. These varieties have a greenish colour due to the presence of granules of epidote or to veins and strings of epidotic material.

v. *South Harris.*

This part of the Outer Hebrides has been examined by Professor Jehu and Mr. Craig,[2] who have obtained important evidence regarding the members of the Archaean Complex and their relations to each other. The results of their work are here briefly summarized.

They have found a mass of anorthosite—a type of rock hitherto unrecorded in any of the Lewisian Gneiss areas on the mainland or

[1] 'Geology of the Outer Hebrides. Part III—North Uist and Benbecula', *Trans. Roy. Soc. Edin.*, vol. liv, part ii (1926), p. 467.

[2] 'Geology of the Outer Hebrides. Part IV—South Harris', *Trans. Roy. Soc. Edin.*, vol. lv, part ii (1927), p. 457.

in the Outer Islands. They have traced two well-marked belts of gneisses of sedimentary origin (paragneisses) which appear to be older than the anorthosite and gabbro-diorite in contact with them. They have described a great development of granite-gneiss intrusive in the older rocks, recalling phenomena in the Lewisian Gneiss of the Laxford district in Sutherland (p. 29).

The small isles in the Sound of Harris contain acid biotite-gneiss with bands of dark hornblende-gneiss and pegmatites, striking north-west and south-east, resembling the rocks in the northern part of North Uist, but differing in a marked degree from those in the south-west part of South Harris.

Two Belts of Paragneisses. The south-west belt of paragneisses, about a mile in breadth, borders the Sound of Harris, and stretches from Rodil in a north-west direction to the promontory of Toe Head; the other crosses the island from Finsbay by the Langavat depression to Borve Lodge on the north-west coast.

The paragneisses of the south-west belt include crystalline limestone, graphite-schists, quartzose rocks, quartz-schists, garnetiferous quartz-schists, garnetiferous sillimanite-gneisses, and garnetiferous kyanite-gneisses, which are associated with gneisses of igneous origin. The rocks have a more or less persistent NNW. strike and have been thrown into sharp folds resulting in the repetition of the limestones and the strata interbanded with them. The best exposures of the limestones are in the neighbourhood of Rodil. Their outcrops are lenticular, due probably to pressure and movement. The limestone in St. Clement's Church quarry is characterized by white nodules of diopside, their greatest diameter being six inches. Under the microscope the rocks show 'abundant rounded grains of forsterite partly serpentinized, a feebly pleochroic phlogopite, clear colourless diopside, and occasionally a little graphite, all these minerals being set in a matrix of granular calcite in which also occurs occasional rhombs of dolomite'. At Obbe, north-west of Rodil, a quartzose rock with garnet and biotite has abundant radiating groups of sillimanite, and on the Chaipaval ridge in the Toe Head peninsula, a similar but more gneissic type contains large garnets with blades of kyanite. The quartzose types of sediment predominate among the beds occurring with the limestones. Some originally have been pure, others felspathic sandstones.

The igneous rocks associated with the altered sediments in the belt bordering the Sound of Harris include hornblendic or pyroxenic gneisses usually garnetiferous. A specimen from St. Clement's Church ridge shows under the microscope 'quartz, andesine, abundant yellow hornblende often enclosing a nearly colourless monoclinic pyroxene'. Another variety near Loch Ossigary consists mainly of hypersthene, a little monoclinic pyroxene, and some green hornblende. It is suggested that some of these igneous rocks may possibly represent metamorphosed lavas or metamorphosed tuffs.

The paragneisses in the north-east belt, ranging from Loch Finsbay to Borve Lodge on the north-west coast, comprises crystalline limestones, quartz-schists, biotite-schists and garnetiferous biotite-schists, striking in a NNW. direction. They are associated with hornblende-biotite-schists and hornblende-schists, the latter evidently of igneous origin.

Anorthosite and Gabbro-Diorite. The area between these belts of altered sediments is occupied partly by a mass of anorthosite and partly by gabbro-diorite. Of special importance is the anorthosite-gneiss, which appears on the south-east coast and is traceable inland by Beinn na h-Aire and Roneval to Loch Steisevat, where it tapers out. Part of the evidence that this mass is intrusive into the paragneisses of the Rodil belt is thus set forth:

'(1) the south-west boundary of the mass runs somewhat obliquely to the strike of the Rodil group of rocks; (2) different members of the Rodil group are seen in contact with the mass or occur within a few yards of it. At Mullach an Stuigha the anorthosite mass is in contact with light and dark hornblendic and hornblende-pyroxene rocks, which are interbanded with the Rodil paragneisses. Again north-west of Mullach an Stuigha the mass is seen to lie within a few feet of an acid-quartzose-gneiss, being separated from it by one of the later dykes.' [1]

This intrusive relationship is confirmed by the occurrence of inclusions of the adjacent rocks in the anorthosite.

Typical specimens of anorthosite show under the microscope that the rock is almost entirely composed of labradorite felspar, with small crystals of hornblende, granules of sphene and grains of epidote.

The mass of gabbro-diorite, which occupies the greater part of the area between the two belts of altered sediments, is a dark-grey rock, containing plagioclase felspar, hornblende, biotite, with some quartz, and usually garnet. The hornblende often contains a core of pyroxene. At some localities it is replaced by eclogite, garnet-amphibolite or garnetiferous hornblende-gneisses.

Ultrabasic Intrusions (Peridotites). Some examples of ultrabasic rocks in the form of dykes or sills have been recorded at various places. Originally these rocks were composed mainly of olivine and pyroxene with iron ores, now largely altered to serpentine. They are schistose along their margins.

Granite-Gneiss and Associated Rocks. Another notable feature of

[1] Ibid., p. 471.

the Archaean Complex in South Harris is the great development of granite-gneiss, intrusive in the older acid biotite-gneisses and hornblende-gneisses. It forms the larger part of the remaining high ground and is prolonged in the north-east part of the isle of Taransay. The foliation is not visible in hand specimens but is recognizable in the field, the strike being north-west and south-east. The rock consists mainly of quartz and various felspars, including microcline, orthoclase, and a plagioclase (albite-oligoclase), together with epidote, biotite, and muscovite; apatite and zircon are accessories. The granite-gneiss is more or less granulitized and shows under the microscope the effects of pressure. The felspars are bent and broken and partly sericitized, and the quartz has wavy extinction.

Pegmatites composed of microcline, orthoclase and a dark mica occur along certain lines, and, like the granite-gneiss, show intrusive junctions with the older members of the complex, and the alteration of the constituents by pressure.

The great north and south belt of crushed rocks and mylonites, so prominently developed in the Barra Isles and in Uist, is traceable at intervals on the promontories on the south-east coast of South Harris and the island of Scalpay. The phenomena, but on a smaller scale, resemble those displayed in the isles to the south and have been caused by movements from south-east to north-west.

INNER WESTERN ISLES PRESUMABLY WEST OF THE MOINE THRUST

i. *Coll.*

Important evidence has been obtained by the Geological Survey[1] in the Archaean Complex of Coll that the gneisses of sedimentary origin (paragneisses) are probably older than the igneous gneisses (orthogneisses) of that island. The dominant members of the orthogneisses are grey hornblende-biotite-gneiss with hornblende lenticles, and typical pink granite-gneiss. The sedimentary gneisses are composed mainly of magnesian marbles, quartz-granulites, and garnetiferous felspar-biotite-granulites, which are associated with bands of hornblende-schist, regarded as igneous intrusions. The banding of these altered sediments is supposed to indicate original bedding planes.

The accompanying map (Fig. 6) shows the distribution of the members of this complex. The eastern part is occupied by grey orthogneiss, the general dip of the divisional planes, with certain exceptions, being east-south-east or east. West of this area the

[1] 'Summary of Progress for 1921', *Mem. Geol. Surv.* (1922), p. 92.

sedimentary gneisses cross the isle in a north and south direction, the dip of the bedding planes being easterly. They are traversed by a belt of pink granite-gneiss running south from Ben Hogh—a hill between Clabhach Bay and Hogh Bay; while still farther west, grey igneous gneiss occurs between the belts of altered sediments trending south from Hogh Bay and Feall Bay.

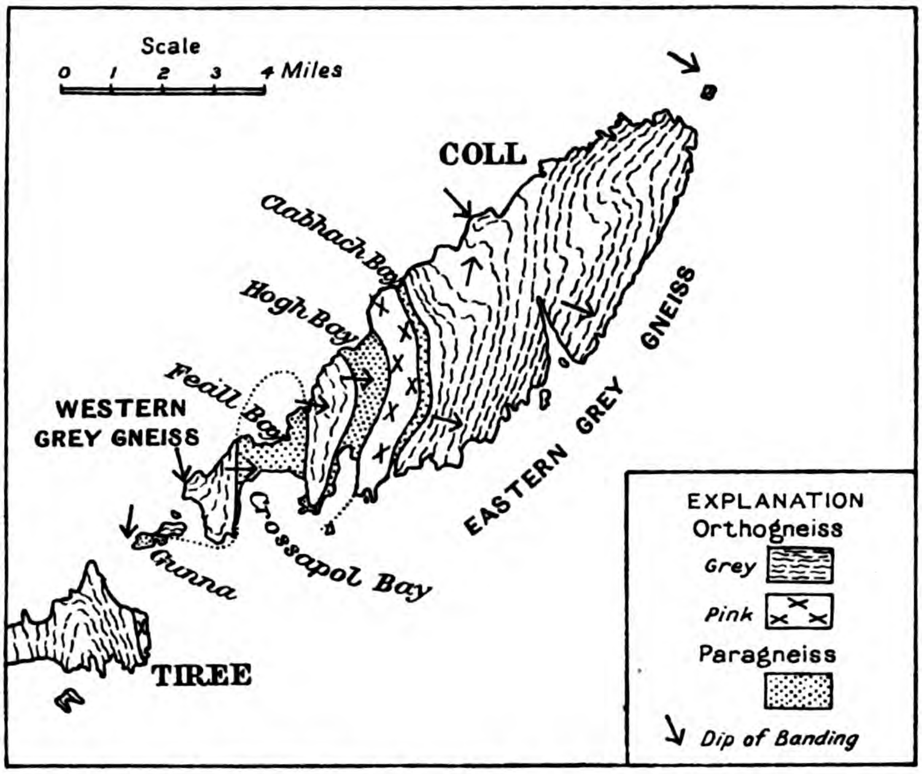


FIG. 6. Map of Lewisian in Coll. (*After E. B. Bailey, V. A. Eyles, and J. B. Simpson, 'Summ. Prog. Geol. Surv. for 1921', Fig. 4.*)

The field relations of the igneous to the sedimentary gneisses are to be seen at several localities. Thus on the west shore of Crossapol Bay, where the main junction between the garnetiferous felspar-biotite-granulites and the orthogneiss is exposed, a band of grey igneous gneiss, about twenty yards wide, occurs within the sediments and envelops many thin layers and lenticles of the felspar-biotite-granulites. Again on the north shore of Hogh Bay, where quartz-biotite-granulite is to be found within a few feet of the granite-gneiss of Ben Hogh, grey igneous gneiss is interposed, which, in places, seems to merge into the rocks on either side, and is xenolithic. One of the pale xenoliths was found to consist of malacolite, basic felspar, calcite, and green hornblende. It is inferred 'that these xenoliths represent impure marbles derived from some portion of the sedimentary belt'. North of Hogh Bay numerous lenticles of felspar-biotite-granulite appear within the belt of Hogh granite-gneiss, and are regarded as fragments of one of the characteristic types of the paragneisses of Coll. These phenomena furnish reasonable ground for the conclusion that the grey igneous gneiss and pink granite-gneiss are later than, and intrusive in, some of the sedimentary gneisses of this island.

ii. *Tiree.*[1]

Since the time of Macculloch the Archaean rocks of Tiree have been familiar to geologists owing to the occurrence there of the pink coccolite marble. The mapping of these rocks by the Geological Survey[2] indicates that the orthogneisses are represented by (1) grey biotite-hornblende-gneiss, (2) black hornblende-schist, (3) pale-grey, pink or red granite-gneiss. These types are intersected by grey and pink pegmatites.

The altered sediments include coarse garnetiferous biotite-gneiss, garnet-biotite-granulite, graphite-schist, pink and grey marble. Special interest attaches to the Tiree marble from its petrographical character and field relations. Professor Sollas and Professor Cole[3] suggested that it might originally have been a coral-sand rock with rounded grains of detrital pyroxene, which had subsequently undergone metamorphism. On the other hand A. K. Coomaraswamy,[4] who has published detailed descriptions of the calcareous rocks, maintains that with the exception of the felspar the Tiree marbles include 'the typical accessory and contact minerals associated with crystalline limestone in all parts of the world'. He shows that the pink variety consists of calcite and subordinate dolomite, with hornblende, coccolite, greenish-brown mica, sphene, and scapolite. The calcareous matrix of the grey marble contains forsterite, mica, tremolite, sahlite, and spinel. He notes that the contact phenomena are masked by the later dynamic movements that affected the marble, and developed in it cataclastic structures resembling those produced experimentally by Adams and Nicolson.

The contacts of marble and gneiss in the Balephetrish district of Tiree were examined by Mr. Bailey and Mr. Eyles of the Geological

[1] Gaelic, *Tireadh*, meaning unknown.
[2] 'Summary of Progress for 1922', *Mem. Geol. Surv.* (1923), p. 91.
[3] 'The Origin of Certain Marbles: a Suggestion', *Sci. Proc. Roy. Dublin Soc.*, vol. vii (1891), p. 124.
[4] 'Observations on the Tiree Marble, with notes on others from Iona', *Quart. Jour. Geol. Soc.*, vol. lix (1903), p. 91.

Survey, who found that the marble, in places, behaves to the gneiss surrounding it like an intrusive rock.

Veins and bands of black and green flinty crush-rock are of common occurrence in the island.

iii. *Iona.*

The greater part of Iona consists of Archaean rocks which are unconformably succeeded by sediments, now regarded as of Torridonian age. The island has been mapped independently by Professor T. J. Jehu[1] and by Mr. E. M. Anderson[2] of the Geological Survey, who have reached similar conclusions regarding the distribution and petrographical characters of the rock-types. The following brief account is based on Professor Jehu's published researches.

The Archaean Complex is composed mainly of orthogneisses, comprising (1) pale-pink or grey quartzo-felspathic gneiss, containing some hornblende and chloritized biotite, with thin folia of dark hornblende-gneiss, (2) basic hornblende-gneisses, with albite as their dominant felspar. Occasional exposures of pyroxene-hornblende-gneiss and garnetiferous pyroxene-granulites have been recorded. The general strike of the members of the complex is north-east and south-west, except in the southern part, where the trend is variable.

The paragneisses of sedimentary origin, which have a limited development, are represented by marbles, calc-silicate-rocks, graphite-bearing rocks, and granulitic biotite-gneiss. The Iona marble on the south coast is a forsterite-tremolite-marble, occurring as lenticles in the gneiss.

The rocks associated with the marble at the marble quarry include the following interesting types: (1) hornfelsed garnetiferous amphibolites, resembling a type found in inliers of Lewisian Gneiss in Central Ross-shire east of the Moine Thrust, (2) a varied series of 'Green Rocks', some of which are probably altered sediments, some altered igneous materials, and some of doubtful origin. Those on the west side of the quarry are described as cryptocrystalline hornfelses.

A prominent massive band of 'White Rock' (pegmatite) runs north from the marble quarry; it is highly granulitized, and merges, in places, into flinty material with a conchoidal fracture. The rock originally was a highly felspathic pegmatite which has been subjected to intense crushing, whereby the original igneous structures have been largely effaced.

[1] 'The Archaean and Torridonian Formations and the Later Intrusive Rocks of Iona', *Trans. Roy. Soc. Edin.*, vol. liii, part i (1922), p. 165.

[2] 'Summary of Progress for 1920', *Mem. Geol. Surv.* (1921), p. 31. See also 'The Geology of Staffa, Iona, and Western Mull', *Mem. Geol. Surv.* (1925).

Unfoliated pegmatites form the latest intrusions in the Archaean Complex, red felspar, usually albite, being the dominant constituent.

No conclusive evidence regarding the relative age of the altered sediments to the prevalent igneous gneisses has been found in Iona, but the mode of occurrence of these altered sediments and their grade of metamorphism have suggested to Professor Jehu that they are younger than, and unconformable to, the orthogneisses.

The members of the complex have been largely modified by pre-Torridonian dynamic movements. The quartz grains show strain shadows, the felspars are broken, and the cracks in the rocks are filled with epidote and chlorite. Mylonization and flinty crush-rock also occur. In some instances the shearing has led to the recrystallization of the original constituents and the development of granulitic gneiss.

A new feature in the history of the Iona Complex is the hornfelsing of the orthogneisses in the south-east part of the Archaean area, and of the 'Green Rock' and garnetiferous amphibolite associated with the marble, observed by Dr. Campbell.[1] It is characterized by the abundant development of new biotite. The hornfelsing of these Archaean rocks, which is later than the deformation of the gneisses in pre-Torridonian time, is evidently due to the Palaeozoic granite of the Ross of Mull, exposed in some of the islets near the south-east coast of Iona.

[1] See *Trans. Roy. Soc. Edin.*, vol. liii, part i (1922), pp. 173, 176, 178.

III

PRE-CAMBRIAN ROCKS

TORRIDON SANDSTONE

WESTERN SEABOARD OF SUTHERLAND AND ROSS, AND SKYE

THE Torridon Sandstone as developed in the North-West Highlands presents features which immediately arrest attention when contrasted with the underlying Archaean rocks. Extending from Cape Wrath on the north coast of Sutherland to Sleat in Skye, with hills rising in places to a height of over 3,000 feet, it consists chiefly of red sandstones, grits, conglomerates and breccias which retain their original characters where not deformed by post-Cambrian movements. This great development of red sandstone was observed by Macculloch,[1] who recorded that it rested with a marked unconformity upon the gneiss. His observation was confirmed by Murchison and Sedgwick[2] in 1827 and by Hay Cunningham[3] in 1841.

Owing to their unaltered character, these sediments were correlated by Murchison and Sedgwick[4] and by Hugh Miller[5] with part of the Old Red Sandstone of Caithness and the Moray Firth basin. This view, however, was shown to be untenable by Nicol[6] and independently by Sir Henry James,[7] who proved that they were overlain unconformably by the quartzite-limestone series to the east, which yielded fossils supposed to be of Silurian age (Plates VIII, 1, and IX). In view of this evidence Murchison[8] grouped the red sandstones with the Cambrian system. The subsequent discovery by the Geological Survey of the Lower Cambrian *Olenellus* fauna in certain bands in the quartzite-limestone series defined the stratigraphical position of the red sandstones as pre-Cambrian. These sediments have since been termed Torridon Sandstone, the name applied to

[1] *A Description of the Western Islands of Scotland* (1819), vol. ii, p. 95.

[2] 'On the Structure and Relations of the Deposits contained between the Primary Rocks and the Oolitic Series in the North of Scotland', *Trans. Geol. Soc.*, Ser. 2, vol. iii, part i (1829), p. 125.

[3] 'Geognostical Account of the County of Sutherland', *Trans. Highland and Agric. Soc.*, vol. xiii (1841), p. 73.

[4] *Trans. Geol. Soc.*, Ser. 2, vol. iii, part i (1829), p. 156.

[5] *The Old Red Sandstone*, 1st ed. (1841), Chap. II.

[6] 'On the Red Sandstone and Conglomerate and the Superposed Quartz-rocks, Limestones, and Gneiss of the North-West Coast of Scotland', *Quart. Jour. Geol. Soc.*, vol. xiii (1857), p. 17.

[7] See *The Life of Sir R. I. Murchison*, by A. Geikie, vol. ii (1875), p. 212.

[8] *Rep. Brit. Assoc. for 1857*, p. 82.

them by Nicol from their great development round the head of Loch Torridon in the west of Ross-shire.

Pre-Torridonian Land-surface. The evidence obtained in the North-West Highlands proves that the Lewisian Gneiss was subjected to prolonged and extensive denudation in pre-Torridonian time. In the tract between Cape Wrath and Laxford the gneiss forms an undulating plateau of more or less uniform height. Southwards, in Assynt, the topographical features are more varied, for, in that region, inliers of gneiss appear partly enveloped in the red sandstones. Thus, on the north-west slope of Quinag a pre-Torridonian hill reaches a height of 1,200 feet above the average level of the adjoining gneiss, against

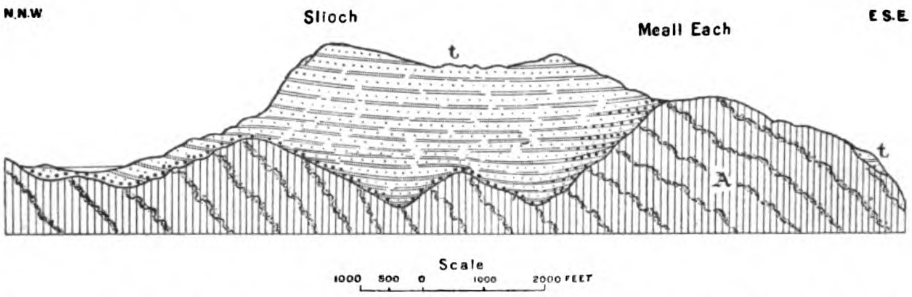


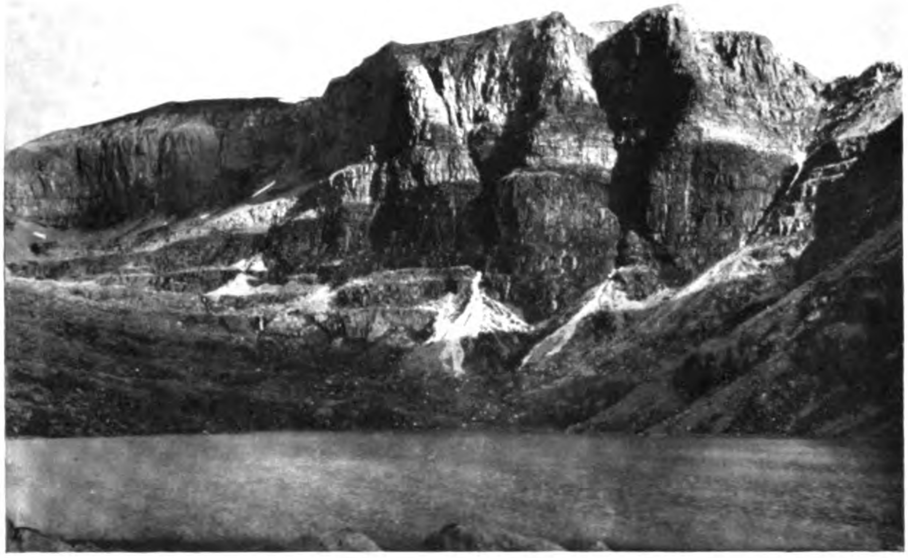
FIG. 7. Section showing Torridonian of Slioch bedded against Lewisian of Meall Each. (*Based on Fig.* 11, '*N.W. Highland Memoir*'.)

which a succession of beds of red sandstone were laid down. Still farther south, between Little Loch Broom and Loch Maree, the old land-surface was carved into hills and valleys, their steep slopes being laid bare by the partial removal of the overlying sediments. An excellent example is to be seen on Meall Each, on the south-east flank of Slioch, north of Loch Maree (Pl. VIII, 2). This pre-Torridonian hill, composed mainly of hornblende-schist, rises to a height of over 2,000 feet, and the old scree-slopes, which supplied the material that now forms the local basal breccia of the Torridon Sandstone, are still visible.

These physical features indicate that the pre-Torridonian land-surface was one of high relief. The evidence furnished by the Torridonian sediments points to the conclusion that they were laid down under continental conditions, from which it may be inferred that the Archaean rocks had a great extension in a north-westerly direction.

The Sparagmite of Scandinavia is an arkose resembling the dominant type of the Torridon Sandstone. It is of the same general age, and has evidently been derived from similar sources in the Scandinavian Shield. In eastern North America coarse sedimentary deposits form part of the newer Algonkian rocks that rise from under-

PLATE VIII



1. Cambrian quartzite unconformable on Torridonian sandstone, Beinn Eighe, SW. of Kinlochewe.

2. Horizontal Torridonian sandstone of Slioch on left abutting against steep side of pre-existing mountain of Lewisian gneiss of Meall Each, NW. of Kinlochewe.

neath the Cambrian strata in the region of the great lakes. These materials were obtained from the great Canadian Shield, which must have formed a large continental area during their deposition.

It is reasonable to infer that those isolated relics of old land-surfaces were united in pre-Torridonian time, thus forming a continuous belt from Scandinavia to North America.

Rocks

The divisions of the Torridon Sandstone established by the Geological Survey are given below in descending order:

3. *Aultbea*[1] *Group* with Cailleach Head beds at top. Sandstone, flags, dark and black shales, and calcareous bands, passing down into chocolate and red sandstones, and grey, micaceous flags with partings of grey and green shale. Thickness 3,000 to 4,000 feet.

2. *Applecross*[2] *Group*. Chocolate and red arkoses with pebbles of quartzite, felsite, jasper, &c. Occasional chocolate and red shales. Thickness 6,000 to 8,000 feet.

1. *Diabaig*[3] *Group*. Hard, fine, red sandstones at top, mixed with red mudstones and dark grey sandy shales with calcareous lenticles. The basal conglomerates and breccias are derived from Lewisian Gneiss. In Skye grey and buff arkoses have a great development with bands of shale. Epidotic grits and conglomerates at the base. Thickness, 500 feet in Gairloch; 7,200 feet in parts of Skye.

The examination of the Torridonian sediments in the field and under the microscope shows that much of the material of which they are composed has been derived from rocks not now exposed in the Lewisian Gneiss areas in the North-West Highlands.

At various localities, breccias, containing angular blocks of the underlying rock, form the local base of the succession, while, at other places, coarse and fine conglomerates occur showing well-rounded stones, many of which are foreign to that region. In the coarse arkoses or felspathic sandstones of the Applecross group, pebbles appear in bands and scattered through the rock. Among the pebbles obtained from the sandstones, grits, and conglomerates, Teall recognized specimens of vein-quartz, quartzite, quartz-schist, chert, jasper, spherulitic felsite, pink mica-schist, quartz-magnetite-schist, quartz-fuchsite-rock, and quartz-tourmaline-rock. He called special attention to the pebbles of spherulitic felsite, as they are identical in all essential respects with the felsite belonging to the Uriconian series in Shropshire. He also recognized microcline, orthoclase, and oligoclase felspars in extremely fresh condition in the coarser-grained rocks.

[1] Aultbea, on east side of Loch Ewe, five miles north-east of Poolewe.
[2] Applecross, a parish extending from Loch Torridon to lower Loch Carron.
[3] Diabaig (Norse, *djúp vik*, deep bay), on north side of lower Loch Torridon.

The epidotic grits and conglomerates at the base of the Diabaig group contain epidote and oligoclase felspar, which may have been obtained from local sources. But throughout the great succession of arkoses in the Applecross division Teall showed that microcline is the characteristic felspar. Microcline might have been derived from the granitic gneisses and pegmatites in the Northern District between Cape Wrath and Laxford, but this mineral is not a common constituent in the gneisses of the Central and Southern Districts.

The microscopic examination of specimens collected from the various divisions of the formation led Teall to the conclusion that the area which furnished the foreign materials must have contained representatives of sedimentary, plutonic, volcanic and metamorphic rocks.

In the finer-grained sandstones lines of heavy minerals occur, which include magnetite, ilmenite, sphene, garnet, tourmaline, zircon, and rutile.

Calcareous layers are extremely rare in the Torridon Sandstone, being restricted to a few thin bands of calcareous grit and lenticles of impure limestone.

Shales appear on several horizons in the Diabaig group, sometimes as thin laminae separating layers of gritty material, sometimes forming bands of considerable thickness. In the pile of red sandstones in the Applecross division they are rarely to be seen in bands, but, in the Aultbea group, at Cailleach Head, they form prominent zones. Ripple-marked, sun-cracked, and rain-pitted surfaces have been found in the shales, flagstones, and well-bedded sandstones.

False-bedding is a characteristic feature of the arkoses of the Applecross division. Diagonal, curved and often reversed lamination is so highly developed that it is difficult, in places, to determine the angle of inclination of the beds. Wind-faceted stones have been observed at certain localities in the grits and conglomerates.

Life

In the shales of the highest division at Cailleach Head—a promontory north of Little Loch Broom—Teall detected phosphatic lenticles and nodules. In microscopic sections of the brown phosphate he observed minute spherical bodies and brown fibres, suggestive of an organic origin. He thus expressed the result of his examination: 'Seeing that phosphates of this type are always associated with organisms, it seems impossible to avoid the conclusion that these peculiar structures are of organic origin; but the evidence at present available is not sufficient to indicate the nature of the organisms.'[1]

[1] 'The Geological Structure of the North-West Highlands of Scotland', *Mem. Geol. Surv.* (1907), p. 288.

The black shales at Cailleach Head are so unaltered that prolonged search in the future might yield organic remains which might be definitely determined.

Distribution and Geological Structure

Cape Wrath to Loch Inchard. In this district no representatives of the Diabaig group have been recorded. The basal conglomerate, which here rests unconformably upon the gneiss, contains well-rounded pebbles of vein-quartz, jasper, chert, felsite, mica-schist, and gneiss, and is overlain by red and purple, false-bedded sandstones and grits with pebbly bands, succeeded by fine-grained, banded sandstones. These strata have been regarded as equivalents of the Applecross and Aultbea divisions, their average thickness being 1,350 feet. They are arranged in more or less parallel belts, trending north-east and south-west, and are truncated by a double system of normal faults. The dip is relatively flat.

Assynt. In this region coarse felspathic sandstones of the Applecross group form a range of hills, including Quinag, Beinn Gharbh, Canisp, Suilven, and Cùl Mòr, once continuous, but now isolated by denudation, and presenting steep escarpments to the west. The beds are generally inclined to the east or south-east, and vary little in character. The base is indicated by breccias and conglomerates of local origin, but, higher up in the series, finer conglomerates appear with well-rounded pebbles of foreign origin resembling those in the Cape Wrath district. Wind-faceted pebbles (dreikanter) occur in these finer conglomerates at the base of the south slope of Quinag.

The coarse arkoses of the Applecross division with their basal conglomerate rest unconformably on the Archaean floor along this range of hills. No members of the Diabaig group have been observed there, but, at Stoer, nine miles to the west of Quinag, they are to be seen in a small outlier of the formation, where they consist of conglomerates, red sandstones, red and green mudstones, with carbonaceous shale and a thin band of limestone, some layers showing worm-tracks and sun-cracks.

Coigach to Loch Maree. Important developments of this system are to be seen in the Coigach Hills and across country southwards to Loch Maree and Loch Ewe. From the head of Little Loch Broom to Ben Slioch at Loch Maree the rocks appear in a range of mountains, the highest being An Teallach, which rises from sea-level to a height of 3,474 feet; two of the peaks are capped by Cambrian quartzite. Remnants of the pre-Torridonian valley system are clearly visible along this range between Loch na Sheallag and Ben Slioch, the existing lines of drainage coinciding in places with those of pre-Torridonian time.

In this wide area the three divisions of the system are represented. Breccias and conglomerates of local origin occur at the base, and, owing to the highly eroded land-surface on which they were laid down, they may appear at any horizon for a distance of 2,500 feet up in the series.

The Diabaig group has here a limited development. The beds form narrow lenticular belts at the base of the succession, which are overlapped by the arkoses of the Applecross division. On the slopes of Beinn Dearg south of Loch na Sheallag they consist of black shales, blue and black greywackes, and flaggy bright-red sandstones, their total thickness being about 250 feet.

The quartzo-felspathic sandstones of Middle Torridonian age occupy the greater part of the area, where they show their characteristic lithological features and the usual assemblage of pebbles of foreign origin. In connexion with these constituents, Professor J. W. Gregory[1] has made an important suggestion. On the north shore of Little Loch Broom, a quarter of a mile west of Badrallach, he collected specimens of pebbles from exposures of the Applecross division which appeared to be indistinguishable from Moine rocks. Teall, who examined five of the specimens and microscopic sections cut from them, stated that all of them could be matched by rocks from areas mapped by the Geological Survey as Moine rocks.[2] Professor Gregory inferred that if pebbles of Moine rocks occur in the Torridon Sandstone it must be a younger formation than the Moine Series. This locality is now about five miles distant from exposures of siliceous granulites of the Moine Series to the east of Badrallach, and about fifteen miles from the sedimentary schists in the Lewisian Gneiss at Loch Maree, another probable source. It should be pointed out, however, that the minimum displacement of the Moine Thrust amounts to ten miles, as proved in the north of Sutherland (p. 118). Hence the original distance may not have been less than fifteen miles.

The thickness of the Applecross group varies considerably in this area. In An Teallach, where the beds are gently inclined to the south of east, the thickness is about 4,000 feet; in the Coigach mountains, where there is a steady south-easterly dip at a low angle for about seven miles, it is about 6,000 feet.

[1] J. W. Gregory, 'Moine Pebbles in the Torridonian Conglomerates', *Geol. Mag.* Dec. VI, vol. ii (1915), p. 447.

[2] Dr. Horne, who also examined the specimens, regarded them as typical siliceous granulites of Moine type.

The members of the highest division (Aultbea), which receives its name from the village of Aultbea on Loch Ewe, appear in Rhu More of Coigach, the Summer Isles, on the promontory of Cailleach Head, Gruinard Island, and across the promontory south of Gruinard Bay [1] towards Aultbea and Isle Ewe. There is a normal upward passage from the coarse felspathic sandstones of the Applecross division into these younger strata, but, in the latter, there is a marked change in the type of sedimentation. The sandstones are finer in grain, they weather with rounded outlines and are associated with prominent bands of shale. An excellent section of these beds is to be seen on the south shore of Rhu More Coigach, near Dorney [2] and Polbain,[3] where they are inclined to the south-east at angles varying from 20° to 30°, their thickness ranging from 3,000 to 4,000 feet. The thickest bands of shale are to be seen at Cailleach Head north of Little Loch Broom, where, as already indicated, they contain phosphatic nodules and lenticles. The shore section displays well-bedded, hard, brown sandstones, green and grey micaceous shales and mudstones, with a band of black shale. The finer sediments are sometimes ripple-marked and sun-cracked.

An important structural feature in this district is marked by a fault, traceable from Baden Bay in Coigach, southwards across the promontory at Cailleach Head and over a tract south of Gruinard Bay to Loch Thuirneag in Loch Ewe. This dislocation has a downthrow to the west of several thousand feet, the upper Torridonian strata on the west side being brought into conjunction with the lowest division of the Torridon Sandstone on the east.

Loch Maree to Applecross. The wide district stretching southwards from Loch Maree by Loch Torridon to the south promontory of Applecross, a distance of twenty-five miles, presents the finest development of the Applecross division in the North-West Highlands. Many of the mountains exceed 3,000 feet in height and furnish striking examples of the great mural escarpments with terraced bars of rock, which are such characteristic features of this formation.

In the Gairloch area the uneven hummocky floor of Archaean rocks is well developed. The basal beds of the Diabaig group lap round the bosses of gneiss and hornblende-schist. Coarse boulder-beds and breccias mainly of local origin occur, the included blocks sometimes measuring five feet in length. In 1880 Sir A. Geikie [4] called attention to this hummocky contour and suggested that it might be due to glacial action, and that the breccia might be of morainic origin. His

[1] Norse, *Grunnforthr*, shallow firth.
[2] Gaelic, *An Doirnidh*, the place of rounded pebbles.
[3] Gaelic, *Am Poll Bàn*, the white hollow.
[4] *Nature*, vol. xxii (1880), p. 400.

interpretation was not confirmed in the course of the survey of that area. No striated rock surfaces nor scratched stones were observed.

The Diabaig group is traceable at intervals from Loch Maree to Loch Torridon. A section of these beds is laid open in the River Lungard at Talladale on the south side of Loch Maree, where the strata consist of greywackes, black and grey shales, and compact brick-red sandstones, about 250 feet thick. An excellent section is to be seen on the north side of Loch Torridon, at the township of Diabaig, from which this division takes its name. Here the basal beds are composed of breccias and flaggy grits, overlain by dark shales and mudstones with flagstones and calcareous bands, succeeded by bright-red sandstones, the series measuring about 700 feet in thickness. The dark shales are ripple-marked and sun-cracked, and, in some places, show rain-pitted surfaces. The variable thickness of this division is due to the irregular surface on which the sediments were deposited.

On both sides of Loch Torridon the Archaean rocks project through the sediments, and the Diabaig beds are overlapped by the felspathic sandstones of the middle division.

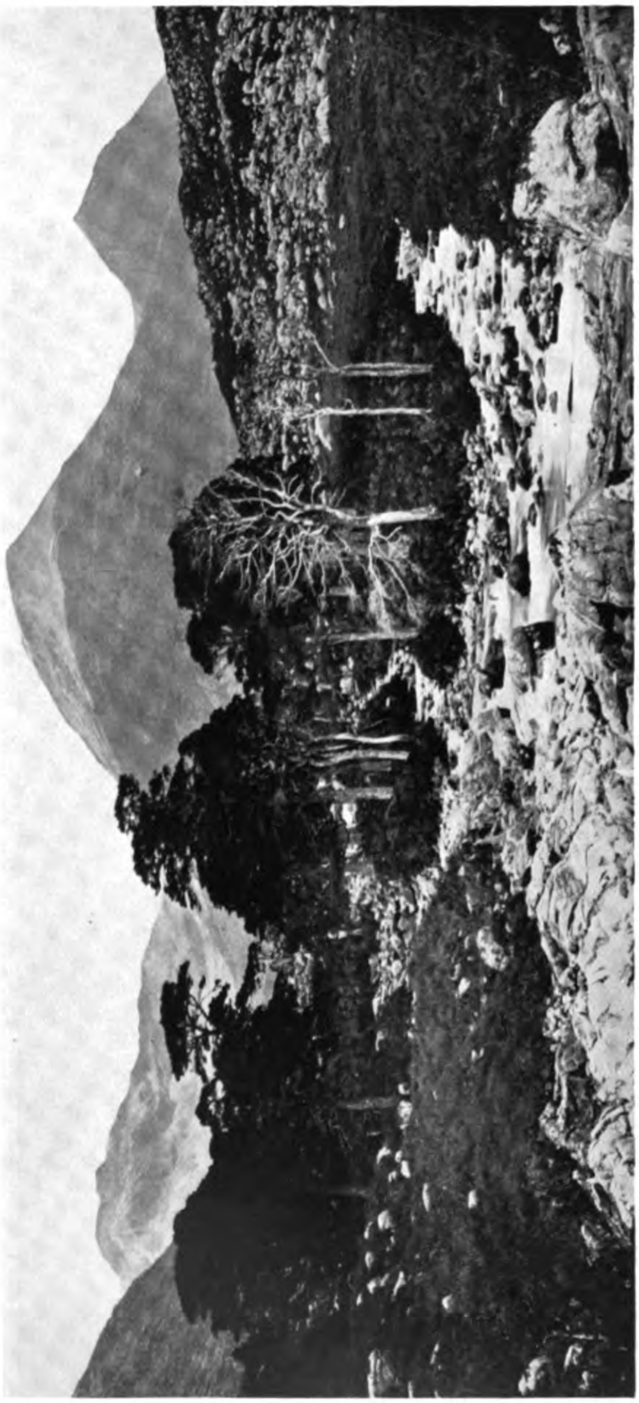
There is little variation in the lithological characters of the Applecross group throughout the high plateau between Loch Maree and Loch Torridon, and in the Applecross mountains. They are composed of massive false-bedded grits and coarse felspathic sandstones, which, in places, alternate with fine-grained sandstones and thin shales. A few scattered pebbles occur, which include felsitic rocks showing fluxion-banding and spherulitic structures, purple quartzite, quartz-schist, jasper, and occasional fragments of gneiss.

An important structural feature traverses the area between Loch Maree and Loch Kishorn. A broad anticlinal fold, affecting the Torridonian sediments and the small outliers of basal Cambrian quartzite resting on the sandstones, extends southwards across Beinn Dearg, Leagach, and Beinn Damph. It is visible on Leagach (Liathach, 3,456 feet), at the head of Loch Torridon, where, in the centre of the fold, the beds are flat and dip away to east and west at low angles. Upwards of 3,000 feet of massive grits and sandstones belonging to the Applecross division are visible on the south slope of this mountain.

In the north part of Applecross the general dip of the strata is towards the west at angles varying from 15° to 25° and the thickness of the arkoses must be about 6,000 feet. In the southern part of the peninsula finer sediments overlie the coarse felspathic sandstones at Loch Toscaig which may represent the Aultbea group.

Several dislocations traverse this area. The most important are: (1) the Fasagh fault, traceable from the mouth of the Grudie River

PLATE IX



MOUNTAIN OF TORRIDONIAN SANDSTONE CAPPED UNCONFORMABLY BY CAMBRIAN QUARTZITE, BEINN EIGHE, SW. OF KINLOCHEWE

on Loch Maree southwards to the head of Loch Kishorn, with a downthrow to the east of more than 1,000 feet; (2) the fault running along the valley of the Applecross River in a NNE. direction to Loch Sheldaig.

Loch Kishorn to Sleat in Skye. The development of Torridon Sandstone described in the foregoing pages lies in the undisturbed area to the west of the post-Cambrian displacements, but, in the district stretching from Loch Kishorn by Loch Alsh to Sleat in Skye, the rocks have been affected by these movements. The Diabaig and Applecross groups occur in that region, but no representatives of the Aultbea division have been recorded. The remarkable feature of the formation in these southern areas is the greatly increased thickness of the Diabaig group as compared with that in the undisturbed areas to the north. This division is typically developed in Skye. The subdivisions of the Torridon Sandstone given below in descending order have been established by the Geological Survey in Sleat:

2. *Applecross Group.* Red arkoses with pebbles of quartzite, felsite, jasper, pegmatite and other materials.
1. *Diabaig Group*:
    - (*d*) Kinloch Beds.—Dark-grey sandy shales and fine-grained grey and buff grits with thin calcareous lenticles.
    - (*c*) Beinn na Seamraig Grits.—Fine-grained grits with bands of grey sandy shale.
    - (*b*) Loch na Dal Beds.—Dark-grey sandy shales with fine-grained grits and small calcareous lenticles.
    - (*a*) Epidotic Grits and Conglomerates.—Beds with abundant pebbles of epidote and epidotized felspar. The finer bands have a green matrix. Occasional purple and green shales.

The general strike of the Torridonian strata in Sleat is north-east and south-west and the dip is towards the north-west. The sequence of the subdivisions is best displayed along a line across the district between Broadford Bay and the Sound of Sleat to Ardnameacan at the entrance to Loch na Dal.

Diabaig Group. The epidotic grits and conglomerates, from 200 to 300 feet thick, have green and yellow tints, the former being due to flakes of chlorite and the latter to small grains of epidote or to fragments of felspar partially converted into epidote. The pebbles consist of white quartz, sometimes seven or eight inches long, blue quartz, gneiss probably of local origin, and rarely pink felsite and quartzite. The abundance of epidote in this basal zone is accounted for by the fact that pre-Torridonian surfaces of Lewisian Gneiss in the North-West Highlands are frequently traversed by thin veins of epidote from which this material may have been derived.

Sandy shales form a large part of the Loch na Dal beds. The shaly layers are interleaved with gritty seams, showing a rapid alternation of fine and coarse materials. Ripple-marks appear on the surfaces of the shales. Massive grits occur especially near the top, where they merge into the beds of the overlying subdivision. A notable feature of the sediments is the occurrence of thin calcareous seams and lenticles, rarely more than six inches thick, in the sandy shales and grits. Occasional layers of magnetite, zircon, and other heavy minerals are to be seen. This subdivision increases in thickness south-westwards from Kyle Rhea to Loch na Dal. At one locality the thickness is estimated at 600 feet.

The distinctive feature of the next subdivision is the great development of grits that form a range of hills from Beinn na Seamraig to Beinn Bhuidhe facing the Sound of Sleat and Kyle Rhea. Near the top, the beds are massive, fine-grained, and greenish-grey in tint. Occasional pebbles are to be seen, some resembling jasper and others containing both quartz and felspar. The finer grits, in places, show clastic grains of iron ore. Bands of shale are interbedded with the grits near the top and bottom of the series. The thickness of this subdivision is estimated at 2,600 feet.

The Kinloch beds occupy a larger area in Skye than any other subdivision of the Diabaig group. They include prominent bands of shale resembling those of Loch na Dal, and the grits, where massive, assume the character of those in the Applecross division. In the grits oligoclase felspar is a more abundant constituent than microcline. Calcareous lenticles and layers containing magnetite and other heavy minerals occur on various horizons throughout the Kinloch beds.

The felspathic sandstones of the Applecross division in Skye are not so coarse-grained as those to the west of the belt of post-Cambrian displacements in Ross and Sutherland. Characteristic features of the arkoses are the false-bedding and the scattered pebbles of red felsite, porphyrite, pegmatite, vein-quartz, jasper, pink and purple quartzite. Dark seams, charged with ilmenite and epidote arranged parallel to the bedding planes, occur in the sandstones. Thin calcareous lenticles have also been observed at a few localities. The thickness of this division is estimated at 5,000 feet, but, as the overlying Aultbea beds are not represented in Skye, the original thickness may have exceeded this amount.

The various subdivisions of the Diabaig group established in Skye together with part of the Applecross division have been traced in the area to the north-east between Loch Alsh and Loch Kishorn, where they overlie the Kishorn thrust-plane and are associated with displaced masses of Lewisian Gneiss. Over the greater part of this area the Torridonian strata are inverted and pass underneath the old Archaean floor on which they were originally deposited.

The epidotic grits and conglomerates charged with epidote and chlorite can be traced continuously round the crag of inverted Lewisian Gneiss, from Fernaig to the valley of Gleannan Dorch, where the rocks have been deformed by post-Cambrian movements. When the inverted base-line is traced northwards beyond Loch Carron the epidotic grits are in places overlapped by the Loch na Dal shales which are in contact with the Lewisian Gneiss. This feature indicates the uneven floor of Archaean rocks on which the Diabaig beds were laid down. This structure recalls the overlapping of the Diabaig beds by the Applecross group in the undisturbed areas north and south of Loch Maree. The other subdivisions of the Diabaig group and the Applecross arkoses form parallel belts to the west of the epidotic grits, where they appear in inverted order, and display lithological characters similar to those in Skye.

Dynamic Metamorphism of Torridonian Strata by Post-Cambrian Movements

Sir J. J. H. Teall has shown that the deformation of Torridonian rocks by post-Cambrian movements is well developed in the thrust areas between Loch Kishorn and Loch Alsh and also to the south of Kinlochewe. In view of Peach's correlation of the Moine Series with Torridonian strata (p. 199), Teall's description of the evidence is here given. It is based on specimens collected partly from Fernaig, Loch Carron, by Peach; partly from the district between Loch Kishorn and Loch Carron, by Sir A. Geikie; and partly from Coulin, near Kinlochewe, by Horne.

'The intensely-sheared epidotic grits which occur at the junction of the Torridonian and Lewisian Gneiss at Fernaig (Loch Carron) contain numerous idiomorphic crystals of magnetite. As these crystals vary considerably in size and are quite unlike the clastic grains of titaniferous iron-ore above referred to, it is probable that they have been developed *in situ*. The secondary micro-crystalline mosaic of this rock, though fine in grain, has all the distinctive characters of a true crystalline schist. Detached flakes of chlorite are scattered through it exactly in the same way as those of mica in typical Moine-schists.'[1]

The medium-grained grits from the district of Lochs Kishorn and Carron, composed essentially of quartz, microcline, and oligoclase, are thus described by Teall:

[1] 'The Geological Structure of the North-West Highlands of Scotland', *Mem. Geol. Surv.* (1907), p. 286.

'The least altered rocks are easily recognisable as grits, but the outlines of the grains are not so well defined as in the unaltered specimens, and a marked fluxion structure is seen on transverse surfaces. The quartz grains have often been drawn out into lenticles and even into thin folia which wind round "eyes" of pink felspar. The hand specimens are traversed by planes of schistosity which are glazed with sericitic mica, and in extreme cases may be termed sericitic schists. Under the microscope the rocks are seen to consist of more or less deformed grains of quartz, alkali-felspar, and oligoclase with a variable amount of secondary crypto- or micro-crystalline material. The series illustrates all the points referred to in describing the effects of dynamic action on quartz and felspar. The secondary crypto- or micro-crystalline material with which the sericitic mica is associated is of special interest because it approximates, in structure, to crystalline schists of the Moine type. It suggests the conclusion that, if the deformation had taken place under a greater load, and therefore in all probability at a higher temperature, a holocrystalline schist of the true Moine type might have been produced.

'Another important series illustrating the effects of dynamic metamorphism near the inverted base line of the Torridon Sandstone near Coulin, over the Kinlochewe thrust-plane, was collected by Dr. Horne. The first of the series is from a point forty feet below the junction line and the others follow in order up to the junction of the two formations. The locality is three miles south of Kinlochewe. The rocks vary in colour from pale pinkish-grey to dark greenish-grey. Dark greenish rocks, weathering to a light cream or buff colour, predominate. They are all more or less schistose, and in texture vary from medium-grained to compact. When the schistosity is even and regular the finer-grained rocks break with a platy fracture reminding one of that of the Moine-schists. The constituents are quartz, microcline, oligoclase, white mica (mostly sericitic), iron-ores (scarce), and a micro-crystalline or crypto-crystalline matrix. Microcline is the dominant felspar. The larger constituents show the pressure phenomena already described, and the quartz grains especially often merge into the crypto-crystalline matrix in such a way as to show that they have contributed to its formation. Flakes of clastic mica may be recognised in some of the finer-grained specimens, but the sericitic mica which is associated with the matrix is mainly of secondary origin.

'The matrix gives a felsitic appearance to many of the hand specimens in which the original structure has almost entirely disappeared. Under the microscope it cannot be resolved into distinct grains. The structure is crypto-crystalline verging on micro-crystalline. It is associated with streaks of sericitic mica. This matrix in which the relics of the original grains are imbedded represents in part finer-grained sedimentary material and is in part of secondary mylonitic origin.

'Looking at the series as a whole, it is noticeable that the least-altered specimens occur furthest from the junction line of the Lewisian and Torridonian rocks, while the most altered specimens are those from its immediate neighbourhood. The increase in alteration is not, however, uniform.

Bands exhibiting the effect of intense shearing alternate with others in which the effects of shearing are much less marked.'[1]

From Kinlochewe[2] northwards to Ben More Assynt, Torridonian strata occur in the various displaced masses lying to the west of the Moine thrust-plane. It is a significant fact that no Torridonian strata occur in any of the thrust masses between the north coast of Sutherland and the Ben More Assynt range—a distance of about thirty miles. They do not appear till we reach the horizon of the materials above the Ben More thrust-plane. The grade of metamorphism produced by the post-Cambrian movements in these rocks is low except at special localities. Where the strata have been made schistose the constituents have undergone partial reconstruction. Thus in Corrie Mhadaidh on the north side of Ben More, the schistose planes pass downwards from the basal Torridonian conglomerates into the underlying gneiss, irrespective of the bedding planes of the former and the original foliation planes of the latter. The grits, sandstones, and shales of the Applecross group have been sheared, the planes of schistosity being more or less parallel with the plane of the Ben More thrust. Larger grains have been partially granulitized and sericitic mica is abundant. Lenticular veins of quartz and felspar appear in the finer bands between the grits.

Summary. From the evidence presented in the foregoing pages it is clear that the various groups of Torridon Sandstone are not equally developed along the belt from Cape Wrath to Skye. The lowest division (Diabaig) does not occur in the Cape Wrath district. In Ross-shire, where it appears, its thickness varies from 250 feet to 700 feet, while in Skye it amounts to over 7,000 feet. The coarse false-bedded sandstones and grits with pebbly bands, which in the Cape Wrath area represent the Applecross group, have an average thickness in that region of 1,000 feet, while in Ross-shire the thickness ranges from 6,000 to 8,000 feet. The upper division (Aultbea) varies in thickness from 250 feet in the Cape Wrath district to 4,000 feet in Ross-shire, but in Skye it is not represented. The irregular distribution of the Aultbea strata is due to the great denudation of the Torridon Sandstone during the interval that elapsed between Torridonian and Cambrian time (p. 91). The extreme lateral variation in the thickness of the beds in the two lower groups is one of the remarkable features of this formation in the North-West Highlands. It points to the gradual subsidence of the uneven land-surface on which the

[1] Ibid., pp. 288–90.

[2] The present Loch Maree was formerly known as Loch Ewe (Gaelic *Loch Iù*); hence Kinlochewe (Gaelic *Ccann Loch Iù*, head of Loch Ewe), now at the head of Loch Maree.

sediments were laid down, and the overlapping of the lower division by the Applecross arkoses in the direction of Cape Wrath (Fig. 8).

The freshness of the felspars and the wind-faceted pebbles (dreikanter) indicate a dry continental climate partly of a desert type. The ripple-marked, sun-cracked, and rain-pitted surfaces of the shales in the Diabaig group in Ross-shire and Skye point to shallow water conditions in the deposition of these sediments. The prevalence of

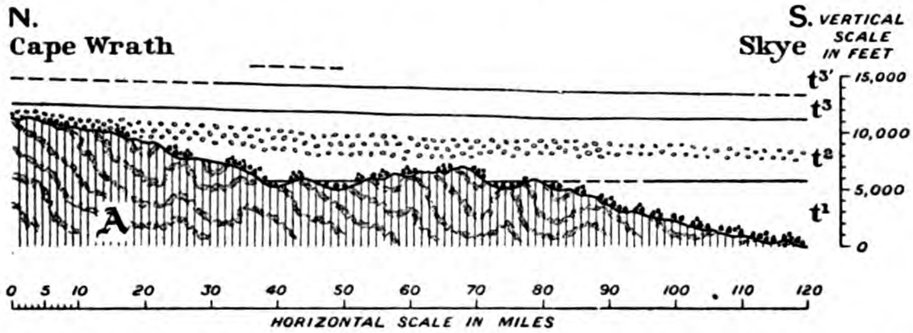


FIG. 8. Diagrammatic section to show local variations of Torridonian. A Lewisian. $t^{1-3'}$ Torridonian: t^1 Diabaig Group; t^2 Applecross Group; t^3 Aultbea Group (with $t^{3'}$ Cailleach Head Beds). Basal breccia shown black. Conglomerate open.

well-rounded stones of local and foreign origin in the sandstones and conglomerates may be due to aqueous action on the shores of an inland lake.

LEWIS

In the neighbourhood of Stornoway there is a small development of red conglomerates resting unconformably on the Lewisian Gneiss, which Murchison and Geikie[1] correlated with the Torridonian conglomerates of Sutherland and Ross. They form detached masses near Swordale and Garrabost on the west side of the Eye peninsula, they appear on the headlands east of Stornoway Harbour, at the Lighthouse on Arnish promontory, and near Coll about two and a half miles NNE. of Stornoway. We visited these exposures in 1911 to compare the rocks with the Torridonian conglomerates of the mainland.

The unconformable junction is well displayed on the shore north of Garrabost, and on the sea cliff SSW. of the township of Swordale in the Eye peninsula. At the latter locality the uneven floor of the Archaean rocks is apparent, for successive layers of conglomerate, which there dip in a westerly direction at an angle of 30°, abut against the gneiss. Rounded and subangular pebbles, composed of acid and

[1] 'On the Altered Rocks of the Western Islands of Scotland and the North-Western and Central Highlands', *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 175.

basic gneiss and pegmatite derived from the Lewisian floor, occur in the deposit. Lenticular seams and nests of soft, chocolate-coloured sandstone are interleaved in the conglomerate. The exposures east of Stornoway Harbour and on the shore at Rudha na Gaoith near Coll furnish confirmatory evidence regarding the local character of the stones and the interstratification of thin seams of soft, friable sandstone. The western margin of the conglomerate is defined by a fault trending north and south, well seen at Arnish south-west of Stornoway Harbour.

The Lewis conglomerate does not resemble the basal deposit with foreign pebbles in the Cape Wrath district of Sutherland, nor the epidotic conglomerate at the base of the Diabaig group in Skye and Ross-shire. It is not unlike some of the basal beds of the Applecross group, but we observed no pebbles of foreign origin in any of the exposures.

The apparent absence of these foreign materials and the decomposed condition of the felspars in the seams of sandstone render the correlation of the Lewis conglomerate with the Torridonian system doubtful. The following passage shows that Murchison realized the uncertainty of his own correlation: [1]

'At the same time it is right to state that the sandy beds intercalated in the conglomerates of the Stornoway headlands are so infinitely less coherent than the red sandstone of the mainland (for the thin courses of sand in the Lewisian beds are rarely in the form of solid stone, but have rather a soft marly character) that some doubt must always remain as to the true age of these insulated deposits.'

No representatives of Cambrian rocks have been found in place in Lewis.

IONA

(*Presumably west of the Moine Thrust*)

On the eastern side of Iona the Lewisian Gneiss is succeeded by sediments, which, in 1911, were correlated by the Geological Survey with Torridonian rocks, as developed in Skye and West Ross-shire. These sediments have been deformed during a period of isoclinal folding with the Lewisian Gneiss, but, as their grade of metamorphism is much lower than that of the members of the Moine Series in Mull, Clough [2] inferred that the Moine Thrust separated the Torridonian strata in Iona from the Moine Series in Mull.

[1] Ibid., p. 176. A. Stevens (*Trans. Geol. Soc. Glasg.*, vol. xv, part i, 1914) has suggested a Triassic age for these beds.

[2] 'The Geology of Colonsay and Oronsay with Part of the Ross of Mull', *Mem. Geol. Surv.* (1911), p. 77.

The following details regarding these Torridonian sediments are based on Professor Jehu's [1] published researches. The rocks are arranged in two divisions as given below.

(2) Upper or Flaggy Group—arkoses, grits, shales and slates, and banded flags.

(1) Lower or Basement Group—breccias, conglomerates, arkoses and grits, with subordinate argillaceous bands.

The beds strike north-east and south-west and dip towards the south-east at rather high angles. The basal breccias and conglomerates of the lower group rest unconformably on an uneven surface of Archaean rocks, and contain pebbles, consisting of red soda granite, gneiss, quartz-syenite (resembling nordmarkite), red pegmatite, aplite, vein-quartz and jasper. These materials, with the exception of the nordmarkite pebble, are evidently of local origin. The prominent constituents in the coarse arkoses and grits are felspars, including microperthite, microcline, orthoclase, and acid plagioclases, ranging from albite to oligoclase. Ilmenite, frequently arranged in layers, is a common ingredient, while sphene, epidote, orthite, zircon and apatite occur as clastic grains in the rocks. The characteristic tints of the members of the lower group are yellowish-green and grey-green due to the presence of epidote and chlorite.

The lower beds of the upper group are composed of rather coarse arkoses, but these are overlain by dark and grey bands of fine arkoses, grits and sandstones with shaly partings. Dark pelitic layers are interbedded with the siliceous flags. The marked feature of this division is its flaggy character due to the rapid alternation of pelitic and arenaceous materials. Felspars, like the varieties found in the lower group, are prominent constituents in the sandy beds. Heavy minerals too occur, like those in the basement division; dark layers, consisting mainly of ilmenite grains, appear in association with much sphene and apatite.

The Torridonian rocks of Iona, and especially near the base of the lower group, display the effects of dynamic metamorphism. The pebbles in the conglomerates and arkoses are elongated and flattened; those of vein-quartz and red felspar are drawn out into parallel rods and streaks. The quartz grains and felspars in the grits and arkoses show brecciation and are partly granulitized. There has been a development of sericitic mica and of secondary epidote and chlorite, resulting from the shearing movement. These features resemble those already described in connexion with the sheared Torridonian rocks west of the Moine Thrust in Ross-shire, produced by the great

[1] *Trans. Roy. Soc. Edin.*, vol. liii, part i (1922), p. 177; see also 'The Geology of Staffa, Iona, and Western Mull', *Mem. Geol. Surv.* (1925), pp. 19–22.

post-Cambrian movements (p. 81). This evidence strengthens Clough's suggestion that the Moine Thrust separates the Torridonian rocks of Iona from the Moine Series in Mull.

The evidence obtained in the field in Iona and from the examination of the rocks under the microscope has led to the correlation of the basement group with the epidotic grits and conglomerates that form the lowest subdivision of the Diabaig group in Skye, and the upper or flaggy beds with some of the Loch na Dal beds in Skye and West Ross-shire (p. 79).

The Torridonian sediments in Iona have been hornfelsed to some extent by the Ross of Mull granite, exposed in Eilean Mòr and other islets near the south-east coast. The slates and shales have been changed into biotite-hornfelses, and the fine arkoses into hard splintery hornfelses with much brown biotite.

IV

CAMBRIAN SYSTEM

WEST SUTHERLANDSHIRE, WEST ROSS-SHIRE AND SKYE

THE quartzite-limestone series of the North-West Highlands, containing the representatives of the Cambrian system in that region, was described by Macculloch, who showed that the strata rest upon the red sandstones and conglomerates (Torridonian) in the west of Sutherland and Ross, and are succeeded eastwards by crystalline schists and gneisses (the Eastern Schists) that stretch across the Great Glen to the eastern border of the Highlands. These observations were confirmed by Murchison and Sedgwick,[1] Hay Cunningham,[2] and Hugh Miller.[3]

Macculloch was the first to discover organic remains in the serpulite-grit, named by Salter *Serpulites maccullochii* (the Salterella quartzite), a persistent zone, which proved of great value in unravelling the structure of the region.

The discovery of fossils in the Durness limestone in 1854 by Charles W. Peach raised problems of prime importance affecting the geology of the Scottish Highlands. Realizing the importance of this discovery, Murchison revisited the area, for he had a vivid recollection of the fact that, in certain sections, the quartzite-limestone series was overlain by the Eastern Schists. Accepting the identification of the fossils by Salter, who recognized their North American affinities, and referred them to the Silurian system, Murchison regarded the quartzite-limestone series as Silurian. He contended that these strata pass *conformably* below, and are overlain by, the metamorphic rocks to the east, and inferred that this metamorphic series must belong to the same system.

On the other hand, Nicol maintained that there is no conformable upward succession from the fossiliferous limestones and associated strata to the overlying schists. The results of his researches, extending over several years, during which he examined the belt between the north coast of Sutherland and Skye, were embodied in a paper[4]

[1] 'The Structure and Relations of the Deposits contained between the Primary Rocks and the Oolitic Series in the North of Scotland', *Trans. Geol. Soc.*, Ser. II, vol. iii, part i (1829), p. 125.

[2] 'Geognostical Account of the County of Sutherland', *Trans. Highland and Agric. Soc.*, vol. xiii (1841), p. 73.

[3] *The Old Red Sandstone*, 1st edition, 1841; and later editions; 'On the Red Sandstone, Marble, and Quartz Deposits of Assynt', published in 16th ed., p. 325.

[4] *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 85.

'On the Structure of the North-Western Highlands, and the Relations of the Gneiss, Red Sandstone, and Quartzite of Sutherland and Ross-shire'. He adopted the following order of succession:

(4) Limestone;
(3) Quartzite (Serpulite-Grit);
(2) Fucoid-Beds;
(1) Quartzite, including the pipe-rock with annelid tubes.
Unconformity
Torridon Sandstone.

His main conclusions may thus be summarized: (1) the limestone is the highest member of the quartzite-limestone series; (2) the Upper Quartzite and Upper Limestone of Murchison's sections are merely the repetitions of the lower quartzite and limestone, due to folds or faults; (3) the line of junction between the quartzite-limestone series and the Eastern Schists is a line of fault, 'everywhere indicated by proofs of fracture, contortion of the strata, and powerful igneous action'. Nicol was in error in regarding portions of the Archaean Gneiss, occurring in the displaced masses, as igneous rocks intruded during the movements, but his main contention that the Eastern Schists do not rest conformably on the quartzite-limestone series has been confirmed by the detailed mapping of the Geological Survey.

Sir A. Geikie, in 1860, traversed rapidly with Murchison the line of junction between the quartzite-limestone series and the Eastern Schists in the county of Ross, where, owing to inversions and overthrusts, the prevalent dip of the fossiliferous strata and the metamorphic rocks is towards the ESE. He was misled by the apparent superposition, and especially by certain deceptive sections in which the Eastern Schists rest with similar dip and strike upon the undisturbed 'Silurian' rocks. Eventually he accepted Murchison's interpretation.

The results of these traverses were communicated to the Geological Society, London, in a joint paper,[1] 'On the Altered Rocks of the Western Islands of Scotland and the North-Western and Central Highlands'. Murchison's interpretation of the structure was therein described, and illustrated by sections, in such convincing form that it met with general acceptance for many years.

The controversy was reopened in 1878, and Murchison's position was shown to be untenable by several investigators. Hicks, Bonney, and Callaway made important contributions to the problem.

Lapworth grasped the true solution of the geological structure of the Durness–Eireboll region. In 1883 he began a series of articles[2]

[1] *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 175.
[2] *Geol. Mag.*, Dec. II, vol. x (1883), pp. 120, 193, 337.

in the *Geological Magazine* on 'The Secret of the Highlands', based upon his detailed mapping of that area in 1882, but, owing to severe illness, this series was never completed. He therein demonstrated the inversion of the 'Silurian' strata on the east side of Loch Eireboll and the unconformable junction of the basal quartzite with the old Archaean floor on the east side of the fault at An t-Sròn.[1] From his paper on 'The Close of the Highland Controversy' (*Geol. Mag.*, 1885) and from the 'Obituary Notice of Charles Lapworth', by Professor W. W. Watts and Sir J. J. H. Teall (*Proc. Roy. Soc.*, 1921), it is clear that he recognized that the Archaean Gneiss had been driven over the fossiliferous quartzite on Ben Arnaboll by a gently inclined overthrust fault. Along this plane of movement, and at other localities, the original rocks had been crushed and rolled out into types, which he termed mylonites. On the shore at Heilim, on the east side of Loch Eireboll, he observed that the serpulite-grit had been repeated many times by faults. All these phenomena were shown in the field in 1883 to Teall by Lapworth.

The Durness–Eireboll region was mapped by us in 1883-4, when we reached conclusions practically identical with those of Lapworth regarding the stratigraphy and metamorphism of the rocks, in complete ignorance of his final results (see 'The Close of the Highland Controversy', p. 98, *Geol. Mag.*, 1885). It was then proved, in the course of the Geological Survey work, that under extreme lateral pressure the rocks behaved like brittle rigid bodies; they snapped and were driven westwards in successive slices, so that crystalline gneiss and schist are made to rest upon fossiliferous strata of 'Silurian' age. It was further shown that the Eastern Schists were driven westward by the Moine Thrust—the most easterly and most powerful of the series—for a minimum distance of ten miles over all underlying thrust masses till they rest upon the unmoved 'Silurian' Limestone in the Durness basin.

The evidence proving these conclusions was carefully inspected in the field by Sir A. Geikie, who previously never had an opportunity of examining the Eireboll sections. He was completely convinced that Murchison's interpretation of the structure must be abandoned, and he took the earliest opportunity of making a public declaration to this effect. A report giving the results of the work by us, with a preface by Geikie, containing a frank confession that he had been misled, and that he had accepted the conclusions of his colleagues, appeared in *Nature*, 13 November 1884.

The discovery of the *Olenellus* fauna in the west of England by Lapworth in 1885 threw light on the stratigraphical position of the

[1] The nose.

quartzite-limestone series of the North-West Highlands. He announced the discovery in a paper[1] in 1888, in which he advanced a classification of the Cambrian rocks in North-Western Europe, the British Islands, and Central and South-West Europe. He therein correlated the strata containing *Salterella* and the *Archaeocyathus* fauna in Durness with the Cambrian system. This correlation was confirmed in 1891 by the important discovery of carapaces of *Olenellus*[2] by A. Macconochie of the Geological Survey in the fucoid-beds in the Dundonnell Forest, Ross-shire, which led to a change in the names of two of the great rock groups in the North-West Highlands. The red sandstones and conglomerates, resting unconformably on

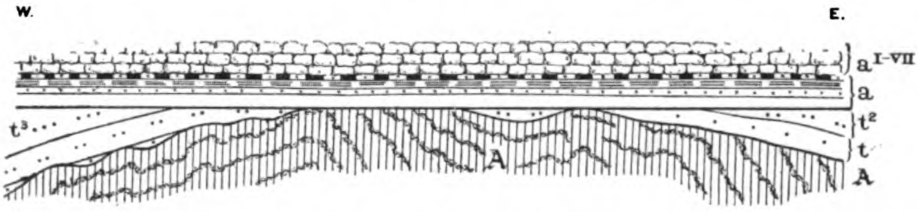


FIG. 9. Diagrammatic section showing Cambrian succession with basal unconformity crossing post-Torridonian folds. 𝔄 Lewisian. t^{1-3} Torridonian: t^1 Diabaig Group; t^2 Applecross Group; t^3 Aultbea Group. a Basal Quartzite, Pipe-rock, Fucoid-beds, and Serpulite-grit of Cambrian (separately ornamented). $a^{\text{I-VII}}$ Calcareous Series of Cambrian as on p. 94. (*Based on Fig.* 16, '*N.W. Highland Memoir*'.)

the Lewisian Gneiss, formerly Cambrian, were termed Torridonian, and the quartzites, fucoid-beds, serpulite-grit, and limestones, were included in the Cambrian system.

Pre-Cambrian Plane of Marine Denudation. The boundary line between the Cambrian quartzites and the Torridon Sandstone is one of the prominent structural features in the North-West Highlands. As already indicated, it marks an unconformity which was established independently by Professor Nicol and Sir Henry James. During this interval of time the Torridon Sandstone was thrown into gentle folds, a great thickness of strata was removed, and the Lewisian Gneiss was exposed over wide areas before the deposition of the marine Cambrian sediments. This denuded plane (Fig. 9) represents the sea floor on which these sediments were laid down. Hence we find the Cambrian quartzites resting in certain areas on Torridon Sandstone, and in others on Lewisian Gneiss. In some instances, the quartzites lie partly on Torridon Sandstone and partly on Lewisian Gneiss in the same line of section—a structure which is known as a double

[1] 'On the discovery of the *Olenellus* fauna in the Lower Cambrian Rocks of Britain', *Geol. Mag.*, n.s., Dec. III, vol. v (1888), p. 484.

[2] 'The Olenellus Zone in the North-West Highlands of Scotland', *Quart. Jour. Geol. Soc.*, vol. xlviii (1892), p. 227.

unconformity. Thus in the areas to the west of the post-Cambrian displacements, between Loch Eireboll and Loch Glencoul, in Sutherlandshire, a distance of about thirty miles, the quartzites rest directly on Lewisian Gneiss, while between Loch Glencoul and Loch Kishorn in Ross-shire the pre-Cambrian floor consists mainly of Torridon Sandstone. The double unconformity is visible on the north slope of Beinn Gharbh, south of Loch Assynt, where the Torridonian sandstones are, bed after bed, transgressed by the overlying quartzites, which eventually rest upon Lewisian Gneiss on the shore of that loch. (*See* Geol. Surv. One-inch Map of the Assynt District.)

These unconformable relations, including the double unconformity, are to be found in some of the thrust masses carried westwards by the post-Cambrian movements. Outliers of Torridon Sandstone have been borne westwards by these movements, thus proving that the formation originally extended far to the east of the belt not affected by these movements.

Rocks

The Cambrian sediments form three divisions, which retain their characteristic features with little variation in thickness along the belt from the north coast of Sutherland to Skye: (*a*) a lower arenaceous series composed wholly of quartzites, about 500 feet in thickness, the upper portion containing vertical worm-casts, termed pipes; (*b*) a middle series, partly calcareous and partly arenaceous, including the fucoid-beds, from forty to fifty feet, and serpulite-grit, about thirty feet; (*c*) an upper calcareous series, comprising dolomites and limestones about 1,500 feet; the total thickness of strata amounting to about 2,100 feet.

The various subdivisions of Cambrian strata in the North-West Highlands established by the Geological Survey are given in descending order in the table on pp. 94–5.

Life

As shown in the vertical section of Cambrian strata (p. 95) the upper subdivision of the quartzites, charged with worm-casts (*Scolithus linearis*), has been arranged by the Geological Survey in five sub-zones, based on a definite order of succession of different forms, probably of specific value. This subdivision has been named the pipe-rock from the prevalence of the vertical cylinders of sand known as pipes. In the third of these sub-zones, specimens of *Salterella* have been obtained; this fossil ranges upwards to the basal Durness dolomites.

In the overlying fucoid-beds, besides the vertical worm-casts, the most characteristic types occur along the bedding planes, known as

Planolites. These flattened worm-casts were at first regarded as fucoids from which the name of the zone was derived. Hingeless brachiopods also occur, including *Acrothele subsidua* and probably *Paterina labradorica*. Of the gasteropods, only one specimen, belonging to a subgenus of *Murchisonia*, has been found on this horizon. *Helenia bella*, a curved calcareous tube, doubtfully referred to the *Dentalidae* by Walcott, is rather plentiful. It has been met with also in the *Olenellus* zone of Newfoundland.

The organic remains that render the fucoid-beds of exceptional interest and importance are the trilobites, because they clearly define the Lower Cambrian age of the strata containing them, and display striking affinities with American types. They are represented by five species and varieties of *Olenellus*, closely resembling the forms in the Georgian terrane or *Olenellus* zone on the east and west sides of the American continent. The genus *Olenelloides* has also been recorded from these beds. The crustacea are represented by phyllocarids, including among others *Aristozoe rotundata*, likewise characteristic of the *Olenellus* zone of North America.

The serpulite-grit receives its name from the occurrence in it of the well-known form *Salterella* (*Serpulites maccullochii*), which is found abundantly in certain calcareous layers that mark pauses in the deposition of the sand. It culminates at the top of the zone where there is a thick carious-weathering band, crowded with specimens of *Salterella*, forming a passage bed at the base of the Durness dolomites. Thin shales interleaved in the serpulite-grit have yielded a fine carapace of *Olenellus lapworthi*.

The dark-blue dolomite, constituting a basal portion of the Ghrudaidh Group, contains two layers charged with *Salterella pulchella*, and *S. rugosa*, both types occurring in the *Olenellus* zone of North America.

The palaeontological evidence indicates that the strata, ranging from the middle of the pipe-rock subdivision of the quartzites to the *Salterella* bands in the basal Durness dolomite, represent in whole or in part the Lower Cambrian *Olenellus* zone of North America.

In the strata overlying the *Salterella* bands, comprising the remainder of the Ghrudaidh Group, the whole of the Eilean Dubh Group, and the lower part of the Sailmhor Group, which consists of dolomites, limestones and cherts with little or no terrigenous material, the only fossils are worm-casts of the nature of *Planolites*, although the limestone and chert may have originated from the debris of the calcareous and siliceous organisms of the plankton. The total thickness of this portion of the calcareous series, yielding no fossils beyond worm-casts, amounts to 350 feet.

(c) CALCAREOUS SERIES	VII. Durine Group.	Fine-grained, light-grey dolomites and limestones, with an occasional fossiliferous band.
	VI. Croisaphuill [1] Group.	c. Fine-grained, cleaved, lilac-coloured limestones, full of flattened worm-casts; fossils deformed by cleavage. b. Alternations of black, dark-grey dolomite and white limestone with an occasional fossiliferous band. a. Massive, dark-grey dolomite and limestone, chiefly composed of worm-casts, which project above the matrix on the weathered surfaces. This is one of the most highly fossiliferous zones in the Durness basin.
	V. Balnakiel Group.	Alternations of dark- and light-grey dolomite, with some bands of limestone, highly fossiliferous; occasional impure unfossiliferous layers with dark cherty nodules. Most of the beds are cleaved.
	IV. Sangomore Group.	Fine granular dolomites, alternating near the top with thin bands of cream-coloured or pink limestone. Near the base are two or more bands of white chert, one about five feet thick.
	III. Sailmhor Group.	Massive, crystalline, granular dolomites, occasionally fossiliferous, charged with dark worm-casts set in grey matrix; large spheroidal masses of chert near the base. This rock is locally known as 'the Leopard Stone'.
	II. Eilean Dubh Group.	Fine-grained, white, flaggy, argillaceous dolomites and limestones with chert bands. No fossils have been found in this division.
	I. Ghrudaidh [2] Group.	Dark leaden-coloured dolomites, occasionally mottled, alternating near the top with white limestone. About thirty feet from the base there is a thin band of dolomite charged with *Salterella* (Serpulites), and a similar band occurs at the base.

[1] Now Croispol.

[2] Now Grudie.

CAMBRIAN STRATA

(*b*) MIDDLE SERIES—partly calcareous and partly arenaceous	Upper Zone. Serpulite-Grit.	At the base lies a massive band of quartzite and grit, passing upwards into carious dolomitic grit, crowded in patches with *Salterella*.
	Lower Zone. Fucoid-Beds.	Dolomitic shales, mudstones, and dolomitic bands, weathering with a rusty colour, traversed by numerous worm-casts, usually flattened and resembling fucoid impressions, yielding *Olenellus*, *Salterella*, *Hyolithes*, &c. Lenticular beds of flaggy dolomitic grit and quartzite are locally developed.
(*a*) ARENACEOUS (QUARTZITE) SERIES	Upper Zone. Pipe-Rock.	5. Massive, purple grit with white pipes. 4. Flaggy quartzites in alternating red and white bands. The pipes are usually wholly white. 3. Quartzites with 'trumpet pipes', which end at the surface of the bed in cup-shaped depressions, sometimes two inches in diameter. These are associated with pipes like those of sub-zone 2. 2. Quartzite with pipes reaching half an inch in diameter. 1. Massive, white or pink quartzites with small pipes one-eighth of an inch in diameter.
	Lower Zone.	False-bedded, flaggy grits and quartzites with a thin brecciated conglomerate at the base, varying in thickness from a few inches to about two feet, containing small pebbles chiefly of quartz and felspar.

Siliceous and calcareous organisms have been obtained in the upper part of the Sailmhor Group. The calcareous forms are represented by (1) gasteropods, including a single specimen of a murchisonid, two species of a pleurotomarid (*Euconia ramsayi* and *E. etna*) of a type occurring in the Calciferous rocks of Newfoundland and Canada; (2) cephalopods, comprising two slightly bent forms with closely set septa and wide endogastric siphuncles that show affinities with those of *Endoceras* and *Piloceras*; (3) arthropods, represented by the epistome of a large asaphoid trilobite resembling that of *Asaphus canalis* of Conrad. This evidence is insufficient to determine the exact horizon of these beds but clearly indicates that they are younger than the strata containing the *Olenellus* fauna. The cephalopods are like those found in the Ozarkian division of Ulrich in North America. According to Schuchert the cephalopods with closely set septa are of Cambrian type, and older than those of the Beekmantown terrane of American geologists. On the other hand, the asaphoid type of trilobite is suggestive of a higher horizon.

The remarkable assemblage of fossils peculiar to the Durness limestone occurs in the Balnakiel and Croisaphuill groups at a height of over 800 feet above the *Olenellus* zone. The total thickness of these two groups is about 550 feet. The Ben Suardal limestones in Skye, which were mapped by the Geological Survey as one division, are regarded on palaeontological grounds as the equivalents of both these groups.

Both siliceous and calcareous organisms are present in this fauna. Among the former occurs *Archaeoscyphia* (Hinde) described by Billings as *Archaeocyathus*, an early Cambrian coral, but shown by Hinde to be a siliceous sponge. The genus *Calathium* is represented by four species. Other genera and species of sponges have been found, so that the siliceous nodules, which are very common in both groups, may be in great part due to them. In support of this suggestion it may be stated that Hinde obtained sponge spicules in some of the nodules.

The characteristic feature of the fauna is the assemblage of calcareous mollusca, comprising lamellibranchs, gasteropods, and cephalopods, showing a wide range of variation, and consequently a long ancestry. The lamellibranchs, though represented only by two genera, *Euchasma* and *Eopteria* of Billings, with several intermediate forms, are of extreme interest as they are known to occur in Newfoundland and eastern Canada.

The gasteropods furnish the largest number of species—about 48 per cent. of the whole. The primitive euomphalids, *Maclurea* and *Ophileta*, are most characteristic. The former genus has a large number of species, many of which are to be found in the Beekmantown limestones of Newfoundland and eastern North America. Only one of the species (*Maclurea peachi*) is peculiar to Durness. Several species of *Ophileta* are met with, some of which likewise appear in the Beekmantown limestone. *Euomphalus* has also been recorded, while several forms belonging to the nearly allied family of the *Turbinidae*, and placed in Lindström's genus *Oriostoma*, are common to these groups and the Beekmantown limestone. Murchisonids and pleurotomarids, numbering twenty-seven species, show a very wide range of variation.

The cephalopods, which are also of primitive type, are represented by several genera, including *Piloceras*, the most characteristic type, associated with *Endoceras*, *Actinoceras*, *Cyrtoceras*, and, doubtfully, *Orthoceras*.

Trilobites are rare in these two groups of dolomite and limestone. They are fragmentary and poorly preserved. Such rarity is one of the disappointing features connected with this remarkable assemblage of organic remains, for the presence of a zonal form would have helped to determine the horizon of these beds. Only one species, *Bathyurus nero* (Billings), has been identified, which also occurs in the Beekmantown limestone of Newfoundland. The other trilobite remains, although poorly preserved, have a Cambrian facies characteristic of North America.

The highest subdivision of the Durness limestone (Durine), measuring about 150 feet in thickness, has yielded two species of murchisonids, *Hormotoma gracilis* and *H. gracillima*, both of which are met with in the underlying groups. *H. gracilis* occurs in the Beekmantown, the Chazy and the Trenton limestones of America.

In connexion with this fauna Peach calls special attention to certain features that throw some light on the absence of calcareous organisms from thick zones of the Durness dolomite and limestone. He has observed that in most cases the septa and walls of chambered shells have been wholly or partly dissolved away, so as to leave only the more massive structures of the siphuncles, and worm-castings are often found within chambers where the septa have been preserved. These features seem to indicate that the accumulation of the calcareous mud in which the fossils were embedded was so slow that there was time for the solution of part of an organism before the whole of it was covered up. There is good reason to believe that many organisms wholly disappeared by this process. Hence it is reasonable to infer that the fossils obtained from the Durness dolomites and limestones cannot be regarded as furnishing a complete life-history of the forms that originally existed in that sequence of deposits.

The palaeontological evidence regarding the relation of the Cambrian fauna of the North-West Highlands to that of North America has led Peach to the following conclusions:

(1) The Lower Cambrian fauna of the North-West Highlands, distinguished by the genus *Olenellus* and its associates, is almost identical in character with that of the Georgian terrane of the western life-province of North America, and essentially different from the Lower Cambrian fauna of Wales and the rest of Europe.

(2) No forms characteristic of the Middle Cambrian division either of Europe or North America have as yet been found in the North-West Highlands, but this division may be represented by the unfossiliferous dolomites and limestones of the Ghrudaidh, Eilean Dubh, and the lower part of the Sailmhor groups.[1]

(3) The fossiliferous bands of the Sailmhor group may be the equivalents of the lower part of the Upper Cambrian formation.

(4) The Balnakiel and Croisaphuill groups of the Durness dolomite and limestone contain a typical development of the molluscan fauna of the Beekmantown limestone, appearing in the eastern life-province of North America, which is regarded by most American geologists as of Lower Ordovician age. But, as the Beekmantown limestone in Newfoundland is overlain by shales with Arenig graptolites, it follows, in accordance with British classification, that these groups belong to Upper Cambrian time. They must represent at least the Tremadoc strata of Wales, if not part of the Lingula Flags of that region.

(5) The highest subdivision of the Durness limestone (Durine) has not yielded fossils of zonal value, and the members of this group are not overlain in normal sequence by graptolite-bearing shale or other sediments.

Distribution

In the belt of Cambrian strata stretching from Loch Eireboll to Loch Kishorn the undisturbed strata are separated from those affected by the post-Cambrian movements by a well-marked line. Owing to the displacement of the rocks caused by these movements, the width of the belt varies considerably in the counties of Sutherland and Ross. In places it does not exceed a mile, while in Assynt it reaches eight miles, the greater part of this broad tract being occupied by thrust materials. In the area of undisturbed strata there is always a normal ascending sequence from the basal quartzites to the outcrop of the most westerly thrust or reversed fault, which may appear in the pipe-

[1] Professor Grabau has given a different interpretation of the absence of Middle Cambrian forms in the Durness dolomite and limestone which is discussed on page 100.

rock, in the fucoid-beds, or in the dolomites and limestones. Within the belt of complication due to thrusts, the structure is unravelled by means of the zonal subdivisions of the quartzites, fucoid-beds, serpulite-grit and limestones, and their relation to the thrust masses of Torridon Sandstone and Lewisian Gneiss.

Durness–Eireboll to Loch Glencoul. The Cambrian strata in the Durness basin, which is the only area in the North-West Highlands that contains a complete sequence of the Calcareous Series, forms an outlier, separated from the main belt at Eireboll by a north-east and south-west fault that brings them against a ridge of Lewisian Gneiss to the east (One-inch Geological Map of Scotland, Sheet 114). The basal quartzites and pipe-rock appear on the higher slopes to the west of the Kyle of Durness, resting unconformably, with an easterly dip, partly on Torridon Sandstone and partly on Lewisian Gneiss—an example of the double unconformity. At the south end of the basin they are followed by the fucoid-beds, *Salterella* grit, and the two lowest divisions of the Calcareous Series (Group I, Ghrudaidh, Group II, Eilean Dubh).

The sequence of dolomites and limestones, ranging from the Eilean Dubh beds to the Durine Group, forming the highest division of the Calcareous Series, is best displayed in the north part of the basin, in the shore section south of Balnakiel Bay, thence eastwards to the village of Durine. The strata dip there to the ESE. at angles varying from 15° to 30°. At the mouth of the Kyle the fine-grained, white, argillaceous dolomites and limestones of the Eilean Dubh Group are exposed on the shore, and on the adjoining island of that name, followed eastwards in normal order by the overlying groups.

The localities where fossils have been found in the highly fossiliferous Balnakiel and Croisaphuill (now Croispol) beds (Groups V and VI) occur in this line of section. For a distance of 400 yards west of Balnakiel Farmhouse the beds of Group V are to be seen on the shore, charged with *Maclurea*, *Murchisonia*, *Ophileta* and other fossils. The members of the overlying Croisaphuill Group form rocky knolls to the east of Loch Croisaphuill and Loch Borralaidh, where they show abundant worm-casts that project on weathered surfaces, and have yielded specimens of *Maclurea*, *Piloceras*, and *Trocholites*.

A noticeable feature of the Ghrudaidh (now Grudie) and Eilean Dubh groups is the occurrence in them of bands of brecciated dolomite on several horizons. Brecciation also appears in the mottled dolomites of the Sailmhor Group on the south side of Balnakiel Bay. In our opinion, however, these bands do not imply any break in the continuous sequence of deposits.

Professor Grabau[1] has called attention to the brecciation visible in the fine-grained, white limestones of the Eilean Dubh Group in the island of that name, at the mouth of the Kyle of Durness. He regards these beds as 'a shallow-water accumulation with occasional hardening of the layers on exposure and the production of intra-formational breccias'. He records the occurrence of a breccia of this type on the east side of that island, and, on the west side, just above high-water mark, he notes 'an interbedded conglomerate, with worn pebbles of limestone generally less than an inch in diameter, the bed varying in thickness from a few inches to a foot'. He states that 'the significance of this conglomerate lies in the fact that it marks a period of distinct emergence, followed by erosion and resubmergence of the region. The magnitude of the hiatus here represented is, however, not apparent; from the physical appearances one would be tempted to assign little significance to it. The fact, however, that the beds some distance above carry a typical Lower Ordovicic (Beekmantown) fauna makes it evident that its significance is greater than would at first appear, for the entire Middle and Upper Cambric is here cut out, indicating a period of prolonged exposure and of non-deposition of the later Cambric strata.' He further suggests that 'it is possible that this conglomerate marks only a minor emergence and that the great break between the Lower Cambric and the Lower Ordovicic is somewhat higher'.

After the publication of Professor Grabau's paper the rocks on the west side of Eilean Dubh were revisited. The long axis of the island runs nearly north and south and measures about 200 yards in length. The beds are exposed on the sea cliff and on the beach at low tide, where they dip to the ESE. at an angle of 15°. The breccia forms a band from two to twelve inches thick, composed of small subangular fragments of dolomite lying in the reddish matrix: it weathers more readily than the underlying and overlying dolomites. When followed along the strike of the beds the breccia gradually tapers out to the north, but there can be no doubt that it indicates slight local erosion of the dolomites. When the ground was mapped by the Geological Survey this feature was regarded as an example of contemporaneous local erosion. The evidence, in our opinion, does not justify the conclusion that it is a break in the succession representing the lapse of Middle and Upper Cambrian time.

In the section describing the life of this formation in the North-West Highlands (p. 98) Peach suggests that the Middle Cambrian division may be represented by the unfossiliferous dolomites and

[1] 'Comparison of American and European Lower Ordovicic Formations', *Bull. Geol. Soc. Amer.*, vol. xxvii (1916), pp. 562–3.

limestones of the Ghrudaidh, Eilean Dubh, and the lower part of the Sailmhor groups. He points out that the forms found in the Balnakiel and Croisaphuill beds are typical representatives of the fauna of the Beekmantown limestone which is regarded by most American geologists as of Lower Ordovician age. He further states that 'as the Beekmantown limestone in Newfoundland is overlain by shales with Arenig graptolites, it follows, in accordance with British classification, that these groups belong to Upper Cambrian time'.

The members of the Durine subdivision (Group VII) are overlain in Sangomore Bay, near the village of Durness, by shattery quartzite, frilled schist and gneiss, overlying the Moine thrust-plane (see section on the geological structure of this district, p. 118).

The eastern slope of the ridge of gneiss separating the Cambrian strata of the Durness basin from those at Eireboll is covered unconformably by the quartzites in normal sequence. The best development of the conglomerate at the base of the series is visible at one point on this ridge, where bands of pebbly grit and fine conglomerate alternate with gritty quartzite for ten feet. The pebbles vary from a quarter of an inch to an inch across, and consist of quartz, felspar, jasper, quartzite, and felsite. The usual thickness of the basal pebbly bed is, however, only about a foot. The felspars of the Lewisian Gneiss, on which the basal quartzites were laid down, have been changed into agalmatolite.

The characteristic feature of the quartzites between the head of Loch Eireboll and Loch More is the great reduplication of the members of this series by overfolds and thrusts, which is well displayed on Arkle near Loch Stack. Among the displaced quartzites on that mountain serpulites (*Salterella*) were found at the top of subzone 3 of the pipe-rock, thus linking this subdivision with the fucoid-beds.

All the Cambrian strata east of Loch Eireboll have been affected by the post-Cambrian movements, and by means of the various subdivisions of the rocks the geological structure of the area has been determined. The members of the Middle Series are exposed on the shore section at An t-Sròn south of Heilim, where fragments of *Olenellus* have been obtained from fine cleaved shale at the top of the fucoid-beds, closely resembling the *Olenellus* layer in the typical section near Kinlochewe, Ross-shire. The *Salterella* grit is there succeeded by the Ghrudaidh and Eilean Dubh dolomites and limestones which occupy a considerable area near Eireboll House.

Between Loch More and Loch Glencoul a few examples of the coarser varieties of the basal conglomerate occur; the bed is at least eighteen inches in thickness, with pebbles, from two to three inches long, of quartz, felspar, and jasper. The line separating the undisturbed from the thrust strata usually appears in the quartzites. Only one exposure of fucoid-beds, and only two exposures of serpulite-grit occur in an unthrust condition, while no portion of the Calcareous Series is found west of the boundary line. Some of the displaced masses contain representatives of the Ghrudaidh and Eilean Dubh dolomites and limestones.

Loch Glencoul to Loch Maree. In the Assynt district the base of the Cambrian rocks is well defined, resting unconformably with a ESE. dip, sometimes on the Archaean floor and sometimes on Torridon Sandstone. The various sub-zones of the pipe-rock, reaching a total thickness of 275 feet, are here typically displayed. The normal ascending sequence is interrupted by thrusting mainly in the fucoid-beds, sometimes in the serpulite-grit, and rarely in the basal dolomites. Fragments of *Olenellus* have been found in soft, cream-coloured shale in the fucoid-beds about three feet from the base of the *Salterella* grit, 200 yards NNE. of Skiag Bridge, on the north shore of Loch Assynt. They have also been obtained at the foot of the Knockan cliff about eleven miles south of Inchnadamff. In the belt of complication a considerable area near Inchnadamff is occupied by dolomites and limestones belonging to the Ghrudaidh, Eilean Dubh, and Sailmhor groups. The tectonic features of this thrust area will be described in the section dealing with the geological structure of the Assynt district (p. 121).

From the Knockan cliff southwards to Loch Maree the belt of Cambrian strata, with some exceptions, varies from half a mile to a mile in breadth owing to the overlap of the Moine Thrust. Throughout this tract the quartzites rest unconformably on Torridon Sandstone. There is, however, clear evidence that the Cambrian strata originally extended much farther west than the present limit of the formation; for near Achiltibuie, to the west of the Coigach Hills, and about nine miles west of the present main Cambrian belt, an outlier of basal quartzite, succeeded by the pipe-rock, is faulted down in the midst of Torridon sandstones (Geol. Surv. One-inch Map of Scotland, Sheet 101).

At various localities near Ullapool and also on the south side of Loch Broom fragments of *Olenellus* have been collected in the unthrust fucoid-beds. Still farther south in the Dundonnell Forest, in Allt Righ Iain, a stream about three miles ESE. of Loch na Sheallag (Geol. Surv. One-inch Map of Scotland, Sheet 92), A. Macconochie first found carapaces of *Olenellus lapworthi* in the fucoid-beds. About three miles south of this locality a carapace of the same form was obtained from thin shales interbedded with the serpulite-grit. Again, in the lower part of Glen Bruachaig, north-east of Kinlochewe, carapaces of *Olenellus lapworthi* and *Hyolithes* were collected from thrust fucoid-beds.

Loch Maree to Loch Kishorn. The best section of trilobite-bearing fucoid-beds in the North-West Highlands is to be found in the belt of undisturbed Cambrian strata south of Loch Maree (Geol. Surv. One-inch Map of Scotland, Sheet 92). It occurs on the northern slope of Meall a' Ghiubhais, a hill formed of thrust Torridon Sandstone, three miles WNW. of Kinlochewe, where a stream-section shows a normal sequence from the *Salterella* grit to the basal quartzites. Though the fucoid-beds occur not far below the outcrop of the Kinlochewe Thrust the fossils are not deformed. From the importance of the fossil evidence, the details of this section are given below in descending order.

Serpulite Grit	*Ft.*	*In.*
7. Blue, clayey, and sandy shale full of small vertical worm-casts; occasional fragments of *Olenellus gigas* and *Olenellus lapworthi*	18	0
6. Shale with well-preserved brachiopods (*Acrothele subsidua*)	0	9
5. Dark, flaggy or platy shale, with fragments of *Olenellus* at base	2	10
4. Yellow, ferruginous, dolomitic band, with conchoidal fracture	0	7
3. Pisolitic ironstone with remains of trilobites and echinoderms	0	2
2. Hard, ferruginous, dolomitic band, the bottom film crowded with carapaces of *Olenellus*	0	3½
1. Soft, jointed, cleaved, clay shale. The topmost seams yield occasional complete specimens of *Olenellus* and fine examples of *Olenelloides armatus*; the lowest two inches are crowded with disjointed and broken segments of *Olenellus*. This band of shale is termed the *Olenellus* layer	0	11

On Beinn Eighe, between the Kinlochewe River and Glen Torridon, the thrust Cambrian strata, composed mainly of the basal quartzites and various sub-zones of the pipe-rock, occupy an area about three miles in breadth. Still farther south in the mountainous ground in the direction of An Ruadh-stac and the Carron valley there is a succession of parallel strips of quartzite with intervening belts of Torridon Sandstone repeated by great folds and thrusts and forming conspicuous features in the landscape. Southwards towards Loch Kishorn to the west of the Kishorn Thrust there is a considerable development of the Ghrudaidh and Eilean Dubh dolomites and limestones, traversed by minor reversed faults.

It is important to note that along the line from Loch Eireboll to Loch Kishorn the highest member of the Calcareous Series is the Sailmhor *limestone (Group III). The overlying fossiliferous zones are not represented.*

Skye. Important evidence regarding the richly fossiliferous zones of the Durness limestones has been obtained in Skye[1] (Geol. Surv. One-inch Map of Scotland, Sheet 71). The Cambrian strata in that island have been folded, and it is probable that all of them have been displaced by post-Cambrian thrusts. They occur in the Ord district south of Loch Eishort, and also near Broadford, where they stretch from Ben Suardal westwards to Loch Slapin, being pierced by the large intrusive mass of granophyre on Beinn an Dubhaich. The basal quartzites and all the sub-zones of the pipe-rock found in Sutherland have been recorded in Skye. The fucoid-beds near Ord have yielded the *Olenellus* fauna, followed by the serpulite-grit containing *Salterella*.

The Calcareous Series is well represented. The following divisions have been established by the Geological Survey:

Cambrian limestone and dolomite	Ben Suardal limestones; probably homotaxial with the Balnakiel and Croisaphuill groups of Durness.
	Strath Suardal and Beinn an Dubhaich limestones.
	Sangomore limestone.
	Sailmhor limestone.
	Eilean Dubh limestone.
	Ghrudaidh limestone.

The limestones cover only about a square mile of ground in the Ord district but the sequence from the Ghrudaidh to the Sangomore group is there represented. The higher members of the Calcareous Series occupy a larger area, about five or six square miles, in the Broadford tract where they have been more folded and deformed than those at Ord. The Ben Suardal limestones are largely developed on Ben Suardal and near Torran on the east shore of Loch Slapin. The stratigraphical horizon of this limestone was first proved by Sir A. Geikie,[2] who obtained the following forms from the outcrops on Ben Suardal: *Murchisonia*, *Maclurea*, *Orthoceras*, and *Piloceras*. This fossiliferous zone is also exposed on the coast near Torran.

[1] See 'Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), pp. 417–27, and 'Geology of Glenelg, Lochalsh, and South-East Skye', *Mem. Geol. Surv.* (1910), pp. 66–71.

[2] 'On the Age of the Altered Limestone of Strath, Skye', *Quart. Jour. Geol. Soc.*, vol. xliv (1888), p. 62.

POST-CAMBRIAN IGNEOUS ROCKS OLDER THAN THE THRUST-MOVEMENTS

One of the fascinating geological features of the Assynt district to which much attention has been paid in recent years is the development of alkaline igneous rocks associated with the Cambrian strata and Torridon Sandstone. The older observers noted their occurrence on several horizons. Nicol[1] recorded that the Canisp porphyry traversed the quartzite overlying the Torridon Sandstone, thus proving that it is later than the quartzite. He also observed the intrusive sheet in the limestone cliff south of Inchnadamff and the igneous mass near Loch Borrolan which he termed felspar-porphyry. Murchison[2] referred to the intrusive rocks near Loch Borrolan as syenites.

Heddle described several varieties of these igneous rocks, ranging from the Canisp porphyry containing porphyritic crystals of orthoclase with albite to the more basic types with hornblende in the Calcareous Series. He pointed out that the igneous rock near Borrolan consists mainly of two constituents, felspar and quartz, and that it has no porphyritic structure. In one of his papers[3] he gives chemical analyses of the porphyritic felspars and of the groundmass of 'a hornstone porphyry' from that district, both of which closely agree with albite in composition. In view of these results Teall stated that 'the credit of establishing the existence of rocks formed by the consolidation of an alkaline magma exceptionally rich in soda, in the Assynt district, unquestionably belongs to Dr. Heddle'.[4]

In 1892 Teall[5] described a group of rocks, which he termed borolanites, collected by the Geological Survey from the intrusive mass in the district of Cnoc na Sròine and Loch Borrolan. He defined typical borolanite as 'a granular aggregate of orthoclase and melanite. Biotite, pyroxene, alteration products after nepheline and sodalite, sphene and apatite, occur as subordinate and variable constituents. The affinities of borolanite are unmistakable. It is a member of the foyaite (elaeolite-syenite) family. The occurrence of melanite as an important accessory in certain rocks belonging to the nepheline-leucite group has long been recognized. In our rock we have melanite raised to the rank of an essential constituent. Borolanite,

[1] *Quart. Jour. Geol. Soc.*, vol. xiii (1857), p. 25, and vol. xvii (1861), p. 99.
[2] Ibid., vol. xvi (1860), pp. 221 and 232.
[3] *Mineralog. Mag.*, vol. v (1884), p. 141.
[4] 'On Nepheline-Syenite and its Associates in the North-West of Scotland', *Geol. Mag.*, Dec. IV, vol. vii (1900), p. 386.
[5] 'On Borolanite: an Igneous Rock intrusive in the Cambrian Limestone of Assynt &c.' (J. Horne and J. J. H. Teall), *Trans. Roy. Soc. Edin.*, vol. xxxvii, part i (1892) p. 163.

as we have already shown, is intrusive in the Cambrian rocks of Sutherland. The nearest rocks in any way allied to it are the elaeolite-syenites of the Christiania district, which are also intrusive in Lower Palaeozoic strata.'

The igneous rocks of this series are all intrusive and occur as plutonic masses, as sheets, and as dykes. Their distribution is well defined. In the area west of the post-Cambrian movements they stretch for about nine miles from Loch Assynt to near Elphin, but in the belt affected by these movements they extend for about twenty-seven miles from Beinn Lice, south of Loch More (Geol. Surv. One-inch Map of Scotland, Sheet 108) to Ullapool. Some of the types appear in the thrust materials carried westwards by the Glencoul and Ben More Thrusts. Near Ullapool, Knockan, and Kinlochailsh they are interleaved in Moine Schists above the Moine thrust-plane.

Plutonic Masses

The plutonic mass of Cnoc na Sròine and Loch Borrolan covers an area from Ledbeg eastwards to a point near the road leading to Loch Ailsh, a distance of five miles (Geol. Surv. One-inch Map of the Assynt District). Owing to the covering of peat, the boundary round part of this area is not well defined. The igneous mass forms a prominent escarpment, which skirts the road leading from Loch Borrolan by Ledmore to Inchnadamff, and rises from the level of about 470 feet to the crest of Cnoc na Sròine (1,306 feet).

Teall has shown that the rock of Cnoc na Sròine varies from a granite to a syenite, and the same variation occurs throughout the greater part of the area occupied by the red intrusive materials. He has stated that the more acid varieties of the red rocks have affinities with the nordmarkite of Professor Brögger. Ferro-magnesian constituents are poorly represented. Two felspars, orthoclase and albite, are present. Sometimes the two felspars are intimately intergrown and assume the character of microperthite. The true syenites, without quartz, contain in places pseudomorphs after nepheline and accessory melanite. Examples of melanite-syenite are recorded by Teall as occurring in the Ledmore River and on the lower slopes of Cnoc na Sròine to the north.

The best exposures of typical borolanite are to be seen in Allt a' Mhuilinn, a stream one mile east of Loch Borrolan, and on the crags to the east. The rock is dark in colour with white, spherical and ellipsoidal patches. Orthoclase and melanite are the chief constituents; biotite is present; pyroxene is rare, but is found in the associated rocks, where it shows characters agreeing with those of the aegirine-augite known to occur in nepheline-bearing rocks. Teall pointed out that the white patches in borolanite are mainly composed of orthoclase and an alteration product, probably after nepheline, and that they correspond to the pseudo-leucites from the phonolites of Brazil and the leucite-syenites of Magnet Cove, Arkansas.

In the course of the survey of the district, a reversed fault or thrust, trending in a north and south direction, was traced at Allt a' Mhuilinn, separating the main area of borolanite to the east from the red granite and syenite to the west. Along this line the borolanite is foliated, the minerals are crushed, and the white spherical patches are drawn out into streaks and lenticles.

The most basic phase of the borolanite magma, described by Teall, was found in a small tributary of the Ledmore River. It is a melanite-pyroxenite, composed mainly of green pyroxene, biotite, melanite, black iron-ores and pyrite.

Teall thus summarizes the results of his examination of the alkaline igneous rocks of Cnoc na Sròine and Loch Borrolan:[1]

'The one mineral which is present in all the rocks of the district is orthoclase. It is found in the most acid granites, and is not entirely absent from the most basic pyroxenite. Between the granite and the pyroxenite are many intermediate varieties, which may be conveniently designated by such terms as syenite, nepheline-syenite, melanite-syenite, melanite-biotite-syenite, augite-syenite, and borolanite. The basic rocks occur on the margins of the main masses and in the outlying satellites.'

Intrusive Sheets and Dykes

The minor intrusions appear mainly as sheets or sills injected along the planes of bedding in the sedimentary strata. They form prominent features in the unthrust Torridon Sandstone and basal Cambrian quartzites to the south of Loch Assynt, of which the Canisp porphyry is a typical example. In the area affected by the post-Cambrian movements the sills have a great development. Two of them occur in the basal quartzites; three in the pipe-rock (the one in sub-zone 3 with 'trumpet pipes' being the most persistent); three in the fucoid-beds; two in the lowest group of the Calcareous Series (Group I, Ghrudaidh); and two in the overlying Eilean Dubh dolomites (Group II). They vary from ten to fifty feet in thickness, and cling to the same horizon for long distances, but sometimes pass transgressively to higher or lower beds. The more acid varieties appear in the quartzite,

[1] 'Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), p. 448.

and the more basic in the fucoid-beds and dolomites. The detailed mapping has proved that the sills were injected into the Cambrian sediments before the post-Cambrian movements affected the region, for, like the beds which they traverse, they are folded and truncated by the major and minor thrusts, and they retain their respective horizons above the great Ben More thrust-plane. In some instances they have been made schistose by the movements.

The most acid rocks are represented by felsites in which the ferro-magnesian constituents are few and usually represented by aegirine. The green variety of aegirine-felsite containing minute needles of grass-green aegirine found on Cnoc na Droighinn, a hill about a mile north-east of Inchnadamff Hotel, is compared by Teall to Professor Brögger's typical grorudite.

Porphyrites of various types are represented. The well-known Canisp porphyry, as described by Teall,[1] is composed of large crystals of albite-oligoclase, measuring half an inch or more across, lying in a red groundmass. Under the microscope aegirine-augite and biotite appear as minerals of primary consolidation. Hornblende-porphyrites containing phenocrysts of oligoclase and hornblende in a dark-green matrix occur in the series. The dark basic sills in the dolomites of the Assynt region, which were originally mapped by the Geological Survey as diorites, include representatives of vogesites and spessartites with idiomorphic green hornblende and both orthoclase and plagioclase felspars.

An important sheet of igneous material occurs in the Oykell valley north of Loch Ailsh among the rocks driven westwards by the Ben More Thrust (see also p. 112). It is separated from the underlying displaced Cambrian quartzites and Lewisian Gneiss by a thrust, and on the south-east side it is overlain by the Loch Ailsh marble. The rock consists mainly of syenite with much microperthite and carbonates after some ferro-magnesian mineral, and iron ores. The material surrounding the basic knots in the mass was termed by Teall[2] an augite-biotite-syenite, having affinities with the augite-syenites of the Oslo district. Along its eastern margin the igneous mass is a hornblendite with pyroxene, and merges in places into an augite-biotite-diorite.

Dykes belonging to this series occur in the Assynt district. An example of the Canisp porphyry type, trending in a WNW. direction, traverses both divisions of the quartzites on the south side of Canisp, and has been traced for a considerable distance across the plateau of Lewisian Gneiss. Examples of dykes of orthophyre occur on Sgonnan

[1] 'Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), p. 451.
[2] Ibid., p. 434.

Mòr, north by west of Loch Ailsh, which Teall regards as a dyke-phase of the syenite magma.

Valuable evidence was obtained in the Coigach district, seventeen miles south of west of Cnoc na Sròine, proving the occurrence there of rocks allied to borolanite, intrusive in the Torridon Sandstone in the form of dykes. The rocks consist mainly of orthoclase and nepheline or its alteration products along with melanite, aegirine, and biotite. The dyke material differs from the typical borolanite at Allt a' Mhuilinn in containing unaltered nepheline and aegirine and less melanite.[1]

Contact Metamorphism of the Cambrian Dolomites and Limestones

The Cambrian dolomites and limestones in Assynt are changed into marble near their junction with the igneous rocks of Cnoc na Sròine, Loch Borrolan, and Kinlochailsh in the Oykell valley. The Cambrian dolomites in Skye undergo a similar change caused by the intrusion of Tertiary igneous rocks. This contact metamorphism was studied by Teall,[2] who found the following minerals in the altered rocks: calcite, dolomite, brucite, diopside, forsterite, serpentine, mica, and tremolite. These minerals were recognized in the marble of Assynt and Skye. Dr. A. Harker has recorded the occurrence of idocrase and garnet in the altered rocks of the latter region.

Next to the calcite and dolomite the most common mineral is brucite, which, Teall suggests, may very probably be a pseudomorph after periclase. The normal pyroxene in the marbles is colourless diopside, but some exceptional types contain another pyroxene, consisting of a green mineral identical with the aegirine-augite of the augite-syenite. The analysis of the aegirine indicates that material has passed from the igneous to the altered rock, but Teall infers that this interchange is confined to the rocks near the junction line. Some varieties of marble are composed mainly of calcite and forsterite with some dolomite, which merge into ophicalcite.

Teall thus summarizes his chief conclusions regarding the Assynt and Skye marbles, that they are, 'for the most part, altered dolomites and that the alteration has been accompanied by dedolomitization, due either to (1) the development of magnesian silicates such as forsterite and tremolite, or (2) to the formation of periclase or brucite'.

Recent Researches in the Alkaline Igneous Rocks in Assynt, Cnoc na Sròine, Loch Borrolan, and the Sgonnan Mòr Plutonic Mass. Professor S. J. Shand[3] communicated the results of his work on this igneous

[1] Ibid., pp. 444–5. [2] Ibid., pp. 451–62.
[3] 'On Borolanite and its Associates in Assynt', *Trans. Edin. Geol. Soc.*, vol. ix, part iii (1909), and part v (1910), p. 376.

complex to the Edinburgh Geological Society in 1908 and 1910. He regards the Cnoc na Sròine intrusion as a laccolite which is composed of several approximately horizontal zones of different composition, the more acid occurring at the top, and the more basic near the floor of the mass. As the passage downwards from one zone to another is gradual, the stratification is supposed to be due to differentiation *in situ*, and not to a succession of intrusive sheets. This passage is exposed in Allt a' Bhrisdidh, a burn which rises near the top of Cnoc na Sròine and flows south-westwards into the Ledmore River. Pink quartz-syenite appears on the hill-top and is visible in the upper two-thirds of the course of the burn, but, as the observer descends the slope, the quartz gradually decreases in quantity and eventually disappears. The rock at this level is highly decomposed, and becomes darker in colour owing to the presence in it of melanite and biotite. Still lower down, and just above the road leading to Inchnadamff, the rock becomes a melanite-augite-nepheline-syenite, which is laid bare along both banks of the Ledmore River, for a distance of half a mile. Professor Shand applies the term ledmorite to this variety. These zones have been traced round the hill and approximate limits are given for their respective heights above sea-level. They are truncated by the north and south thrust-fault at Allt a' Mhuilinn whereby the basic rocks of the lower zones have been raised to a level higher than that of the transition zone on the west side of the displacement. This interpretation of the structure of the mass is shown in the accompanying sections illustrating Professor Shand's paper (Fig. 10 A and 10 B).

In the exposure at Bad na h'Achlaise (Fig. 10 B) the rock is a melanite-pyroxenite whose essential constituents are aegirine-augite, melanite, biotite, ilmenite, apatite and pyrite. It is termed cromaltite, the name being derived from the adjacent Cromalt Hills. It there occurs in contact with limestone, and on analysis shows an exceptionally high lime content. The chemical evidence suggests assimilation of lime by the igneous mass, but the field evidence is too inconclusive to show whether assimilation has modified the composition of the laccolite.

Petrographical descriptions are given by Professor Shand of the rocks forming the main intrusive mass and the dykes of the border zone, from which it would appear that he regards the majority of borolanites as melanite-nepheline-syenites. He also imposes the following limitations on the use of the name borolanite: (1) rocks containing less than about ten per cent. by volume of melanite have been termed melanite-syenite and nepheline-aegirine-melanite-syenite, (2) rocks containing aegirine-augite in addition to (and replacing) melanite, and which lack the spotted porphyritic character may, if desired, be

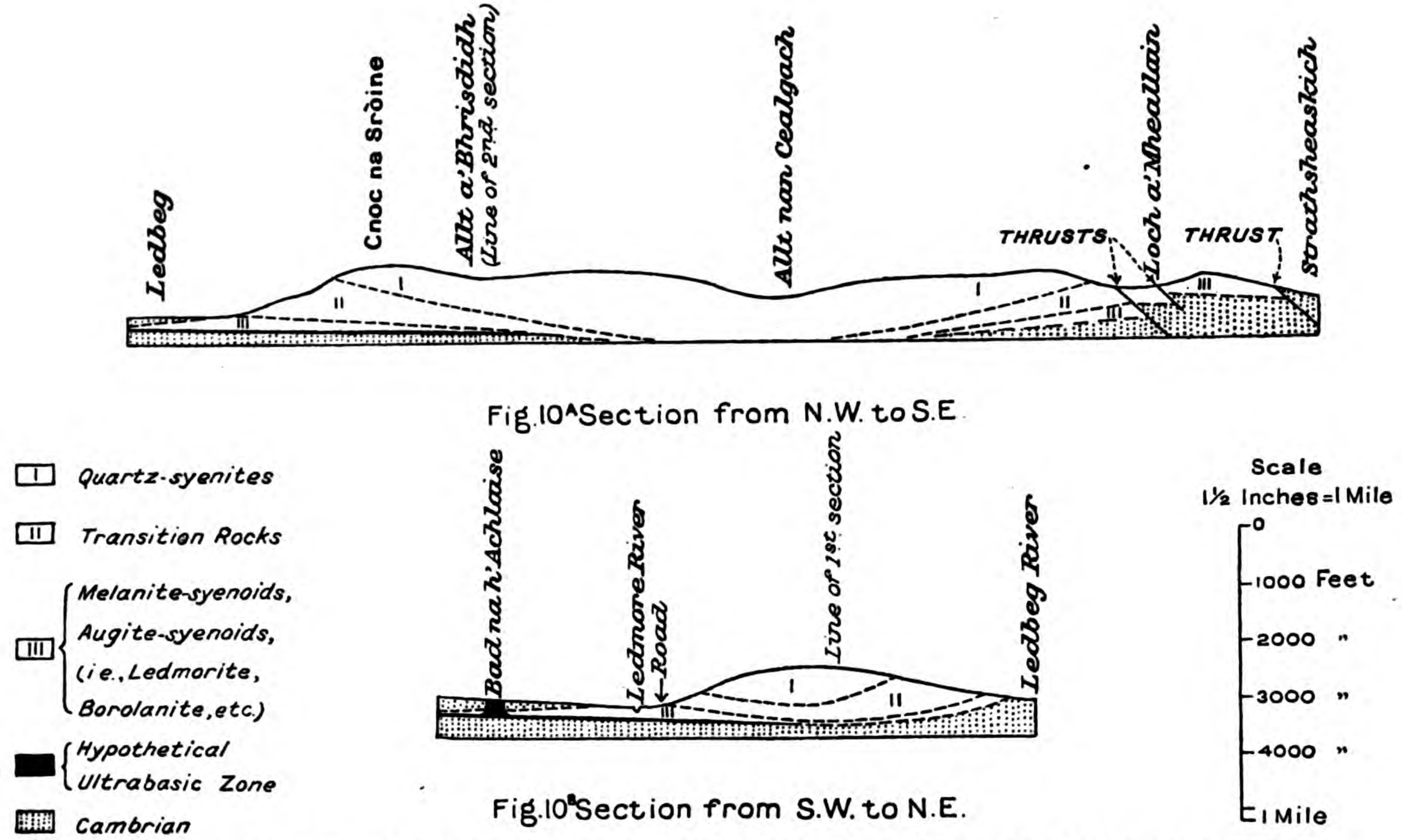


FIG. 10. Sections across Cnoc na Sróine laccolite. (*After S. J. Shand, 'Trans. Edin. Geol. Soc.', vol. ix, p. 379.*)

regarded as a sub-group of borolanite. According to these limitations the term borolanite is restricted to rocks containing more than ten per cent. by volume of melanite.

Loch Ailsh Igneous Mass. The igneous mass at Kinlochailsh, north of Loch Ailsh, in the valley of the Oykell, has been recently mapped by Dr. J. Phemister of the Geological Survey, and has been described in great detail by him in the memoir[1] descriptive of Sheet 102 of the Geological Survey One-inch Map of Scotland. Some of the results of his work are here briefly presented.

The mass contains a large number of rock-types. The Plutonic Group includes perthosite (a pure alkali-felspar rock), aegirine-melanite-syenite, nordmarkite, pulaskite, riebeckite-syenite, shonkinite, hybrid rocks, biotite-pyroxenite, and hornblendite. The Hypabyssal Group comprises grorudite, bostonite or lindöite, nordmarkite-aplite and porphyry.

The new name perthosite is introduced for plutonic igneous rocks consisting of alkali-felspar with less than three per cent. of mafic minerals. The alkali-felspar includes both orthoclase and albite, which may be present separately, perthitically intergrown, or intergrown as cryptoperthite or anorthoclase.

The igneous mass is regarded as a composite laccolite injected into the Cambrian sediments, the pipe-rock lying beneath the intrusion and the Durness limestone above it. Patches of quartzite, fucoid-beds, serpulite-grit, and limestone are enclosed in the igneous rock.

Coarse-grained pyroxenite and hornblendite occur at the base of the mass and are overlain by a discontinuous zone of fine-grained shonkinite and pulaskite. Next in order comes a discontinuous layer of nordmarkite and pulaskite. These three zones form the earlier intrusion with a probable maximum thickness of 300 feet. Before the complete consolidation of this material a minor injection of perthosite, producing the peculiar features of the basic knots, is postulated.

Overlying the earlier intrusion, and containing fragments derived from it, is a great mass of perthosite which occupies a large part of the area. On Sail an Ruathair it merges laterally into aegirine-melanite-syenite, the latter rock forming the south peak of that ridge. This peak, about a mile and three-quarters north by east of Loch Ailsh, is supposed to represent the pipe through which perthosite was erupted, but in which the aegirine-melanite-syenite subsequently consolidated. These two types constitute the later intrusion of the Loch Ailsh mass. The eruption of these later materials was followed by the injection of dykes and veins of grorudite, bostonite (lindöite),

[1] 'The Geology of Strath Oykell and Lower Loch Shin', *Mem. Geol. Surv.* (1926), pp. 22–111.

nordmarkite-aplite, and porphyry. The accompanying section illustrates Dr. Phemister's interpretation of the structure of the mass (Fig. 11).

The basic knots, which are well developed in the River Oykell below its junction with Allt Sail an Ruathair, are composed of rocks varying from pulaskite with about 30 per cent., to shonkinite with about 70 per cent., of dark minerals. The knots are supposed to have originated through the disruption of the first intrusion by a local injection of perthosite magma, which took place when the rocks of the early intrusion were still in a plastic condition. Some of the materials are regarded as hybrid types. From the detailed examination of the basic knots Dr. Phemister has found 'that (*a*) the very dark shonkinite is unaltered, (*b*) the dark, patchy, basic knots are greatly altered, but the degree of alteration is less in the more shonkinitic patches, (*c*) medium-coloured, patchy types are thoroughly altered throughout, (*d*) the light-coloured types are patchily altered as if the invading rock had not been able to affect them entirely'.

Evidence is obtained on Sròn Sgaile, an isolated intrusion about two and a half miles north-east of Loch Ailsh, that the rocks of this hill have been altered by dynamic metamorphism. The base of the mass is formed of ultrabasic material, and the upper part of grey, felspathic hornblende-rock with poikilitic biotite, both types being traversed by syenite veins. Petrographically the rocks resemble epidiorites. They also possess features that link them with some of the igneous types of the Loch Ailsh laccolite. In the field the mass is truncated on three sides by thrust-planes, and the rocks on the west face are highly sheared and partially mylonized. The deformation of the rocks on Sròn Sgaile is what might be expected in view of this evidence.

The contact alteration of the Cambrian sediments by the igneous rocks of Loch Ailsh is clearly shown in the patches of quartzite, fucoid-beds, and especially in the Durness dolomites enclosed in the mass. The types of altered dolomites are arranged in five groups according to the prevalence of one of the following five minerals, olivine, pyroxene, amphibole, mica, or carbonate. Phemister finds that, in addition to diopside, mica is one of the chief products in the contact alteration of the sedimentary patches enclosed in the igneous material; and that the permeation of the sediment by the igneous rock has led to chemical reaction between the potash-felspar of the syenite and the magnesia of the dolomite, resulting in the formation of a magnesian mica. He therefore infers that another method of dedolomitization should be added to those enumerated by Teall (p. 109), viz.: 'by absorption of potash-felspar and the formation of a potash-magnesia-mica'. The igneous rock, also, has been altered by the transfer of material from the sediment accompanied by reaction. The igneous rock absorbs lime with the formation of the calcium-aluminium silicates, grossularite, vesuvianite, and zoisite; where the iron-bearing pyroxene, aegirine-augite, has entered into the reaction, the calcium-iron-aluminium silicates, melanite and epidote have been formed.

Regarding the origin of the alkaline magma of the Loch Ailsh laccolite, Dr. Phemister infers that it is not due to absorption of the Cambrian dolomite. The evidence indicates that assimilation of lime by the igneous rock has taken place only to a limited extent, and that in cases where assimilation has been effected the resultant rocks are abnormal types. He believes that the alkaline character of this mass is original, and suggests that the syenite of Cnoc na Sròine may in like manner have been formed from an original, alkaline magma.

POST-CAMBRIAN MOVEMENTS

The North-West Highlands have become a classic region for the demonstration of the effects of earth movements on a remarkable scale. Certain features, characteristic of these movements between the north coast of Sutherland and the southern promontory of Skye, a distance of 120 miles, have been established by the Geological Survey.

Features Characteristic of the Post-Cambrian Movements.

1. By lateral compression of the earth's crust, the rocks have been thrown into a series of folds, usually inverted, and accompanied by reversed faults or thrusts (Pl. X). The general strike of these folds and thrusts is NNE. and SSW., and the general dip of the axial planes of the folds, the reversed faults, and the strata is ESE. The middle limb of the overfold is attenuated, and may develop into a reversed fault.

2. Without incipient folding, the strata are repeated by minor thrusts or reversed faults, which lie at an oblique angle to major thrust-planes. These are also inclined to ESE., the direction from which the pressure came.

3. The following structures have been produced by major thrusts of varying magnitude: (*a*) certain beds of the Cambrian formation have been heaped up and driven westwards along planes in the underlying undisturbed materials; (*b*) slices of Lewisian Gneiss with the overlying Torridon Sandstone and Cambrian strata override the piled-up rocks beneath; (*c*) the Eastern Schists have been driven far to the west, till, in some instances, they rest upon undisturbed Cambrian rocks.

4. Owing to the movement of rocks from east to west and the

PLATE X

OVERFOLDING AND THRUSTING OF TORRIDONIAN (DARK) AND CAMBRIAN (LIGHT), BEINN LIATH MHÒR, ACHNASHELLACH

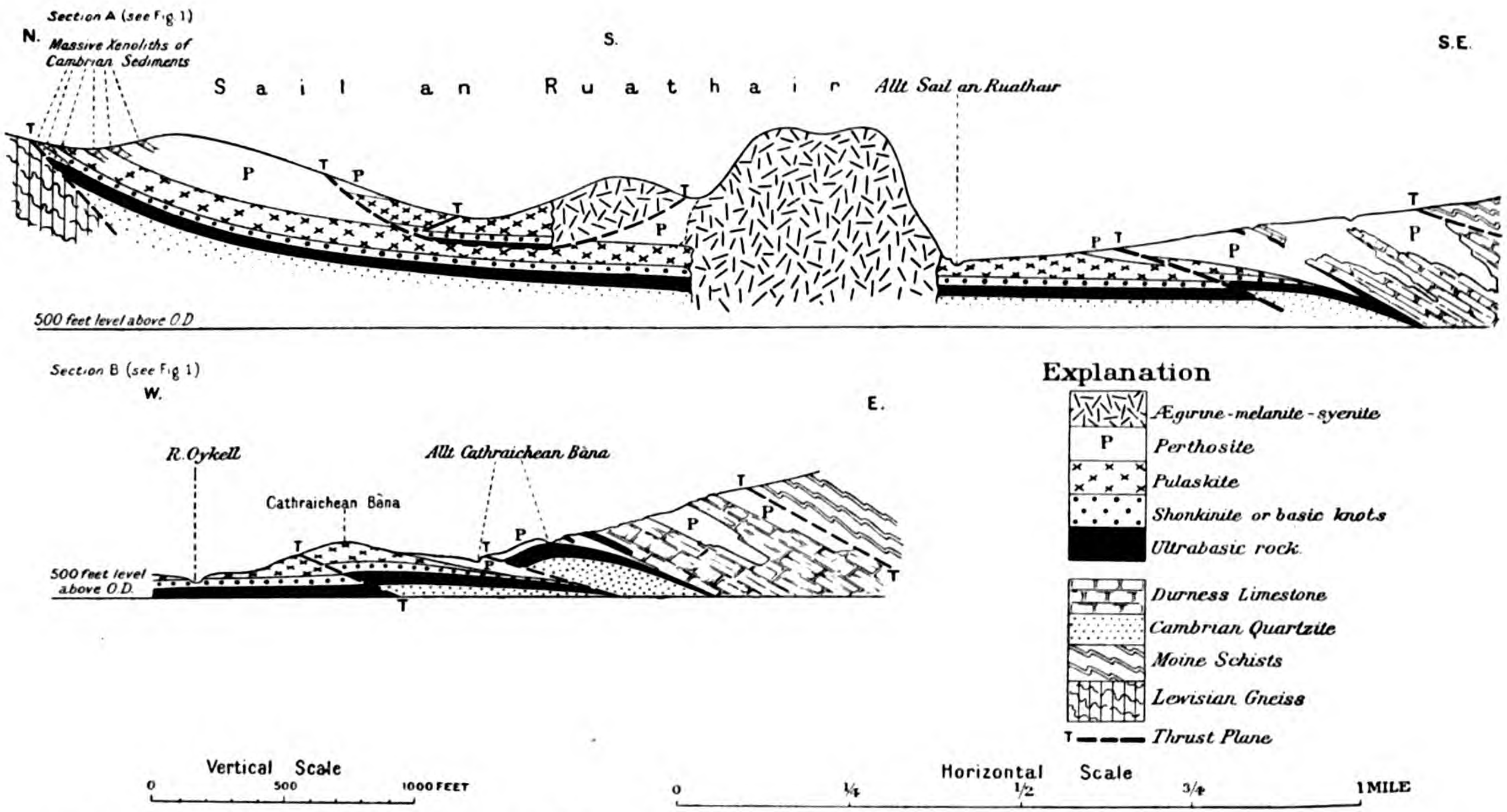


FIG. 11. Diagrammatic sections across Loch Ailsh intrusion. (*After J. Phemister in 'Geology of Strath Oykell and Lower Loch Shin', Fig. 2.* For lines of section see map, Fig. 1, op. cit.)

friction along the plane of the thrust, the materials, in some instances, folded over and curved under the advancing mass, thus producing inversion of the strata.

5. By denudation, outliers of thrust materials have been formed, which are separated from the rocks below the plane of disruption by a dislocation with circular outcrop.

The structures to the west of the great thrusts present two main types: (1) the reduplication of the strata, consisting mainly of Cambrian quartzites or alternations of quartzites and Torridon Sandstone, by overfolds and to a certain extent by reversed faults; (2) the piling-up of fucoid-beds, serpulite-grit, and basal dolomite, by reversed faults without incipient folding (Imbricate Structure, *Schuppen Struktur*), the thickness of these sediments amounting to about 100 feet. The dip of the reversed faults and of the intervening strata is towards the ESE.

The structures characteristic of the great thrusts vary according to the nature of the materials in each thrust mass. The rocks in the more westerly group consist of Lewisian Gneiss, Torridon Sandstone, and Cambrian strata, or of Lewisian Gneiss and Cambrian strata alone. These displacements have received local names from the areas where they are typically developed, as, for instance, Arnaboll, Glencoul, Ben More, Kinlochewe, Kishorn, and Ben Suardal in Skye. These great displacements cannot be traced continuously along the belt of complication, but it is probable that the Ben More, Kinlochewe, and Kishorn Thrusts may be on the same horizon.

The materials carried westwards by the Moine Thrust, the most easterly of the great lines of disruption, are composed of mylonized rocks, quartz-schists, mica-schists, garnetiferous muscovite-biotite-schists, and lenticular masses of acid and basic gneiss of Lewisian types. In their crystalline condition these materials differ completely from those in the great thrust masses to the west. This plane of movement is usually accompanied by mylonites (Lapworth), which make it difficult, in some instances, to determine the exact position of the plane of movement. But, as a rule, the Moine thrust-plane is well defined along the line of outcrop, where not concealed by glacial deposits.

Evidence has been obtained indicating that the minimum extent of the horizontal displacement of the rocks by the Moine Thrust amounts to about ten miles. It is difficult, if not impossible, to form any reliable estimate of the maximum extent of this displacement.

Metamorphism resulting from the Post-Cambrian Movements. The deformation of the rocks within the belt of complication to the west of the great thrusts is of minor importance. New structures first appear along the great lines of disruption, where the Lewisian Gneiss above the planes of movement is sheared and merges into flaser-gneiss, passing ultimately into a platy schist. The pegmatites show fluxion structure with felspar 'eyes'. Where the thrust Lewisian Gneiss is covered unconformably by Torridon Sandstone or Cambrian quartzite, new schistose planes have been developed in the gneiss near the line of junction.

These phenomena are more conspicuously developed as the observer approaches the outcrop of the Moine Thrust, and especially in connexion with that plane of movement. The basic and acid gneisses and pegmatites are sheared, and merge into green, grey, and pink mylonites, the colour varying according to the nature of the materials from which they were derived. The false-bedded grits and quartzites have been sheared and crushed. The grains of quartz and felspar in these rocks have been elongated, and there is a marked development of sericitic mica. The vertical annelid tubes in the pipe-rock have been bent over in a westerly direction and flattened like ribands. The sills in the Torridonian and Cambrian sediments are likewise deformed. The pink felsites have been changed into sericitic schists, and the hornblende-porphyrites into green chloritic schists. The new divisional planes in gneiss, pegmatites, Torridonian and Cambrian sediments, and intrusive sills alike, are more or less parallel with the great planes of movement.

Some of the remarkable structures characteristic of the post-Cambrian movements in the North-West Highlands have been reproduced experimentally by H. M. Cadell.[1] His experiments show the development of imbricate structure, and the inclined thrust-plane or 'sole' along which the heaped-up strata were driven. Regarding these structures he was led to the following conclusions:

1. Horizontal pressure applied at one point is not propagated far forward into the mass of strata.

2. 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.

3. 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.

Age of the Movements. Definite evidence relating to the age of the movements has been obtained. As already indicated, they must be later than the alkaline igneous rocks, which are intrusive into the Cambrian sediments in Assynt. It is also certain that they must

[1] 'Experimental Researches in Mountain Building', *Trans. Roy. Soc. Edin.*, vol. xxxv, part i (1889), p. 337.

be older than the Old Red Sandstone in the county of Sutherland, as the basal conglomerates of that formation rest upon the eroded edges of the Eastern Schists and contain pebbles of basal quartzite, pipe-rock, dolomite and limestone derived from the Cambrian rocks of the North-West Highlands.

Geological Structure.

Along a belt of complication between the north coast of Sutherland and Skye, certain areas illustrate the structures more clearly than others. The following typical sections are selected for detailed description: (1) the section across the Durness–Eireboll region, as it is the only area where the minimum displacement of the rocks for about ten miles by the Moine Thrust can be proved; (2) certain sections in Assynt, because in that district the sequence of the great thrusts and their characteristic structures are more clearly displayed than in any other area in the North-West Highlands.

Durness–Eireboll District. The distinctive structural features of the Durness–Eireboll region are: (*a*) the occurrence of two powerful thrusts, one on Beinn Arnaboll (Beinn Poll Ath Roinn in Sheet 114), east of Loch Eireboll, bringing forward a slice of Lewisian Gneiss with the overlying Cambrian strata, ranging from the basal quartzites to the Eilean Dubh dolomite (Group II of the Calcareous Series), and the Moine Thrust; (*b*) the great overlap of the Moine Thrust whereby the rocks above that plane pass transgressively across all underlying displaced masses till they rest upon the highest subdivision of the Calcareous Series (Group VII) in the Durness basin (Geol. Surv. Sheet 114).

West of the Kyle of Durness the uneven floor of the Lewisian Gneiss is overlain on Meall Sgribhinn by Torridon Sandstone (t^2), the latter being covered unconformably by the Cambrian quartzites (*a*). On the west shore of the Kyle the red sandstones are overlapped by the quartzites which there rest directly upon the gneiss. At the head of the Kyle the zones of the pipe-rock are succeeded by the fucoid-beds, serpulite-grit, and the Ghrudaidh dolomite (I), the zones being concealed in the line of section by the sea-loch. The various subdivisions of the limestone (I—VII) follow in normal order till we reach a point east of the village of Durness, where the highest subdivision of the dolomites and limestones (VII) is overlain by mylonized rocks, shattery quartzite, marble, schists, and deformed gneiss lying above the Moine thrust-plane. Here the passage from the Durness dolomite upwards into the Eastern Schists appears to be quite conformable but it is entirely deceptive, for the thrust materials can be linked with the corresponding section on Fair-aird Head

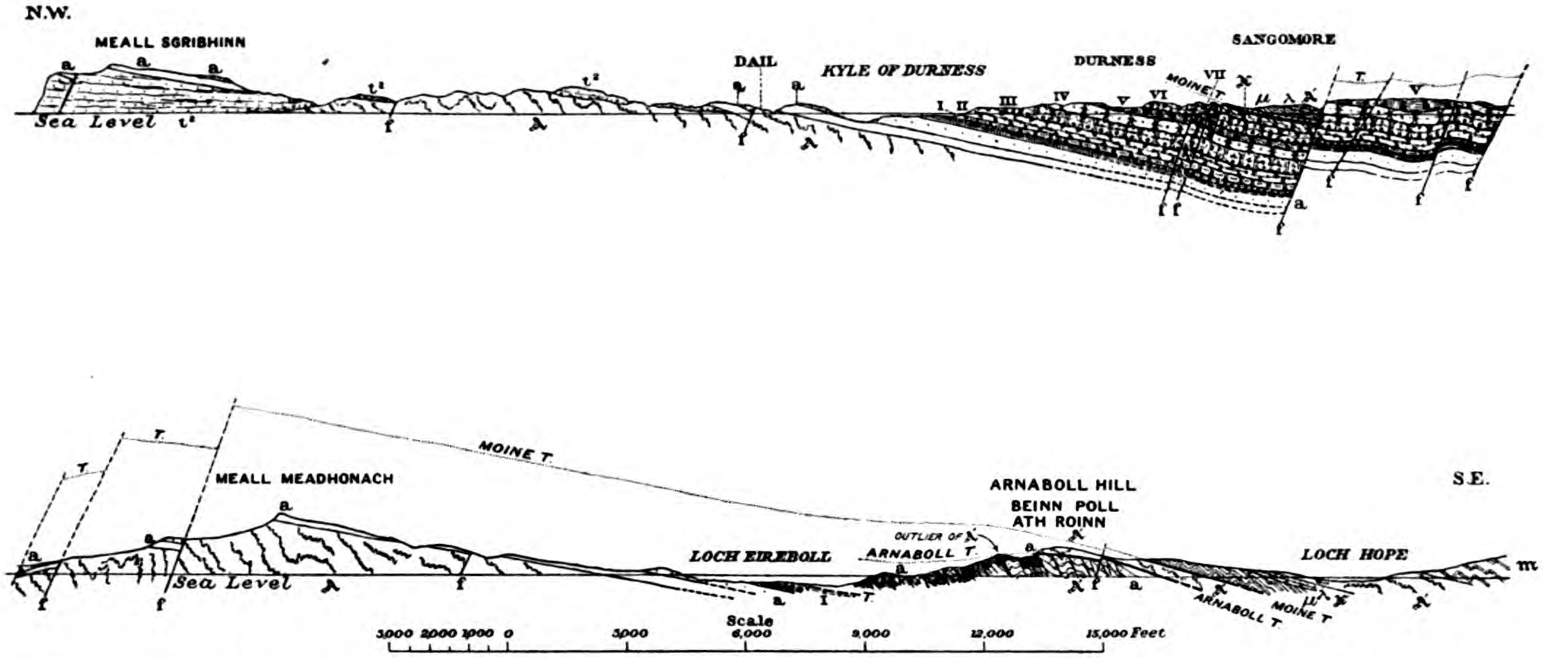


FIG. 12. Section showing Moine Thrust in Durness–Eireboll district. 𝔄 Lewisian Gneiss, (𝔄′ where thrust). t² Applecross Group of Torridonian. a Basal Quartzite, Pipe-rock, Fucoid-beds, and Serpulite-grit of Cambrian. I–VII Groups in Calcareous Series of Cambrian. μ Mylonized Rocks, Green Schists, and Phyllites. 𝔪 Moine Schists. 𝔛 Quartz-schist. λ Marble. T Thrusts. f Faults. (*After* '*N.W. Highland Memoir*', *Fig.* 20; Meall Sgribhinn now written Sgribhin-bheinn.)

north-west of Durine village, and with the sequence overlying the Moine thrust-plane east of Loch Eireboll.

Along the east side of Sango Bay, at Sangomore, the patch of Eastern Schists is thrown down against the Durness dolomite (Fig. 12), and to the east of the limestone plateau we meet with two powerful normal faults, which separate the Cambrian strata of Durness from those in Eireboll. The more easterly of these two step-faults (west of Meall Meadhonach) lets down the quartzites about 1,200 feet to form a small outlier, and the more westerly one serves as boundary to the Cambrian outcrop of the Durness basin.

The Lewisian Gneiss on the eastern slope of Meall Meadhonach, in the Eireboll district, is covered with the basal quartzites, followed in normal order by the lower zones of the pipe-rock. On the east shore of Loch Eireboll and to the north of Heilim, there is a fine development of imbricate structure due to the piling-up of fucoid-beds, serpulite-grit, and basal dolomite, by reversed faults inclined to the ESE. at a slightly higher angle than the dip of the strata. Between Heilim and Arnaboll Hill (Beinn Poll Ath Roinn) the zones ranging from the Eilean Dubh dolomites to the pipe-rock are repeated by reversed faults and overfolds. This reduplication clearly illustrates the piling-up of the strata in advance of the Arnaboll Thrust (Fig. 12) which has driven westwards a slice of Lewisian Gneiss about 400 feet thick in places, with a patch of basal quartzite on the western face of the mass. This displaced gneiss rests upon all the Cambrian zones ranging from the basal quartzite to the *Salterella* dolomite at the base of the Ghrudaidh Group.

On the north slope of Arnaboll Hill the vertical worm-tubes in the pipe-rock beneath the thrust gneiss are flattened and bent over towards the west, in the direction of movement. The basal quartzites beneath the mass are sheared, and the divisional planes are streaked with parallel lines produced by the movement. New structures have been developed in the gneiss and pegmatite near the thrust-plane, but in the centre of the mass the original characters of the rocks are preserved.

About half a mile north-west of Arnaboll Hill there is a small outlier of sheared gneiss, about 100 yards long, separated by a dislocation with circular outcrop from the underlying piled-up fucoid-beds, serpulite-grit, and dolomite. This patch indicates the former extension westwards of the Archaean rocks above the Arnaboll thrust-plane.

The displaced gneiss on Arnaboll Hill is truncated by the Moine Thrust which ushers in the mylonized rocks, marble, deformed gneiss, and Moine Schists that occur at Durness near the village

PLATE XI

1. Distant view across Loch Glencoul from south. Lewisian gneiss (𝔄′) is thrust on to Cambrian (a) resting unconformably on Lewisian gneiss (𝔄).

2. Near view at head of Loch Glencoul. Lewisian gneiss (dark) thrust over basal Cambrian quartzite (pale).

EXPOSURES OF GLENCOUL THRUST-PLANE

and east of Fair-aird (Faraid) Head. These detached masses of the Eastern Schists in the Durness basin, once continuous with the main belt east of Loch Eireboll, but now isolated by denudation, furnish striking proof of the horizontal displacement of the rocks by the Moine Thrust.

Assynt District. The tectonic features of the Assynt district may thus be summarized: (1) the occurrence of the Glencoul, Ben More, and Moine lines of disruption which follow each other in definite order from west to east, the Glencoul Thrust bringing forward Lewisian Gneiss covered unconformably by Cambrian strata, the Ben More Thrust carrying forward a slice of Archaean rocks and Torridon Sandstone both overlain by Cambrian quartzites, and the Moine Thrust ushering in the Eastern Schists; (2) the great overlap of the Moine Thrust which passes transgressively across all the underlying displaced materials till the schists above that plane rest directly upon undisturbed Cambrian strata (Fig. 13).

(a) Glencoul Thrust. The structures connected with this line of disruption are admirably displayed on both sides of Loch Glencoul, where they form conspicuous features in the landscape which immediately arrest attention. The accompanying section (Fig. 14 and Pl. XI, 1) shows the relations of the strata on the north side of that sea-loch. At the western limit of the section the undisturbed Lewisian Gneiss (𝔄 Fig. 14) is covered unconformably by the basal quartzites, the zones of pipe-rock, and the fucoid-beds (all lettered a, but separately ornamented), in regular order. The normal sequence is interrupted on the last horizon by the first thrust or 'sole', along which have been driven fucoid-beds, serpulite-grit, and basal dolomite, repeated by reversed faults, thus furnishing a fine example of imbricate structure. These piled-up strata are truncated by the Glencoul Thrust, which brings forward a huge slice of Lewisian Gneiss (𝔄′), about 1,500 feet thick, with its associated north-west basic dykes. This line of disruption is laid bare on a hill slope on the south side of the sea-loch, where the accompanying photograph (Pl. XI, 2) was taken. Immediately above the thrust-plane the strike of the gneiss is deflected and the rock is rolled out into a platy schist parallel with the plane of movement, but in the heart of the mass the gneiss retains its original characters and north-west strike.

On Glas Bheinn and Beinn Uidhe SSE. of Loch Glencoul (Fig. 13), this slice of the Archaean rocks is covered unconformably by the basal quartzites and pipe-rock, which, when traced southwards towards Inchnadamff, fold over and buckle under the gneiss, appearing there in inverted order above the Glencoul thrust-plane.

(b) Ben More Thrust. This line of disruption introduces new

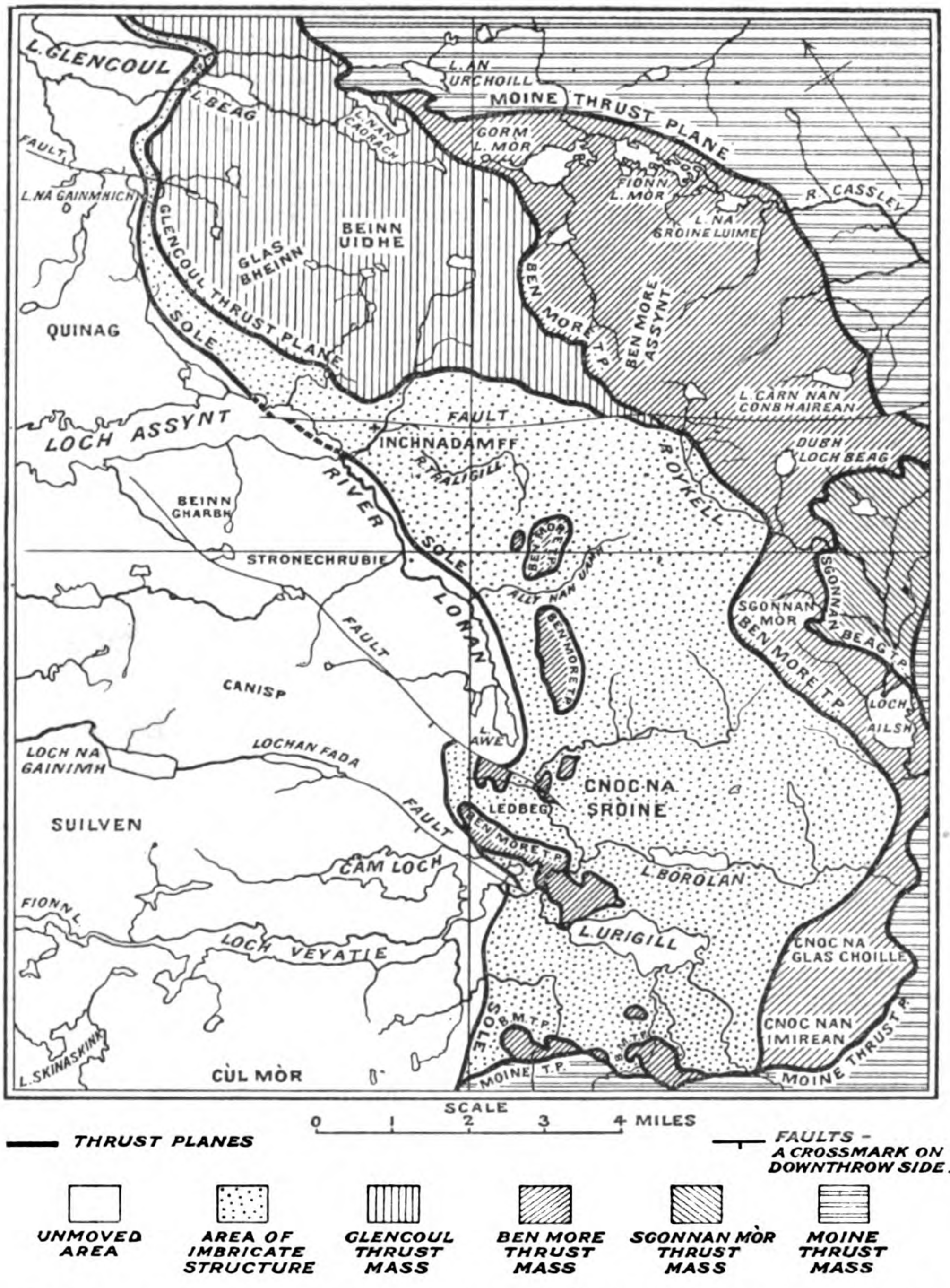


FIG. 13. Sketch-map of thrust-masses in the Assynt district. (*After 'Guide to Geol. Model Assynt Mountains', Fig. 3.*)

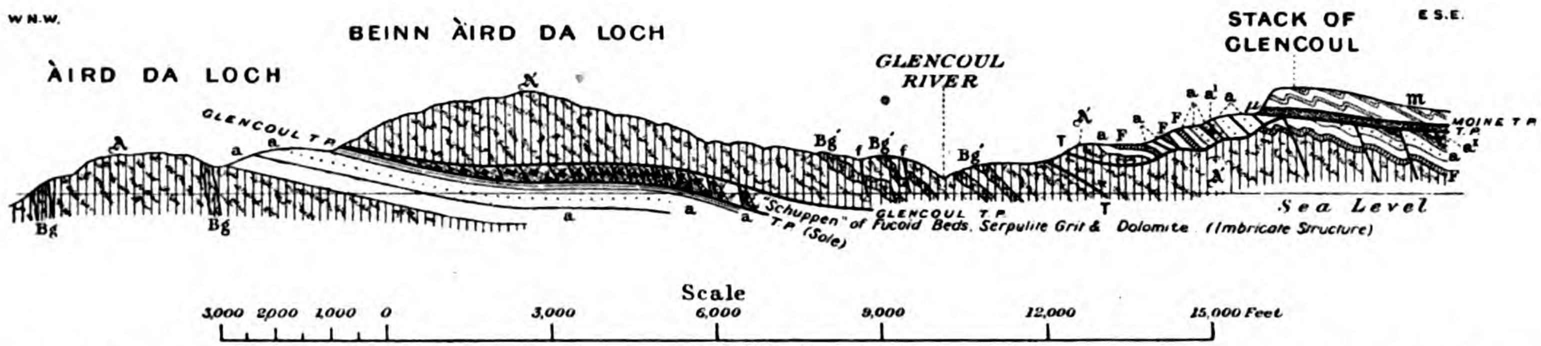


FIG. 14. Section through Glencoul and Moine Thrusts, N. side of Loch Glencoul. 𝕬 Lewisian Gneiss with Bg Basic Dykes (𝕬′ & Bg′ where thrust). a Basal Quartzite, Pipe-rock, Fucoid-beds, and Serpulite-grit of Cambrian. a¹ Dolomite (Ghrudaidh Group of Calcareous Series of Cambrian). μ Mylonites. 𝔪 Moine Schists. F post-Cambrian Intrusions. T and T.P Thrust-planes. f Faults. (*After 'Guide to Geol. Model Assynt Mountains', Fig.* 5.)

features in the tectonics of the Assynt region. As already indicated, it brings forward another great slice of Archaean rocks, covered unconformably by Torridon Sandstone and with the Cambrian quartzites lying unconformably upon both the Lewisian Gneiss and Torridonian strata. These features are clearly displayed in the deep corrie (Dubh Loch Mòr) on the south side of Ben More (3,273 feet). Here the Lewisian Gneiss with its basic dykes forms a dome-shaped flexure showing the unconformable Torridonian sediments, with a well-marked conglomerate at the base, folding over the western front of the mass and dipping in inverted order beneath the old floor. This inversion can be traced for a considerable distance along the east side of the Oykell valley. On the eastern ridge of Ben More, the thin covering of quartzites on the crest of the fold has been largely removed by denudation. These displaced materials have been driven westwards across underlying Cambrian strata ranging from the false-bedded quartzites to the basal dolomites of the Calcareous Series.

The Glencoul Thrust is overlapped by the Ben More Thrust near the Beallach of Conival, a mountain pass at the head of the Oykell valley (Fig. 13). Owing to its gentle inclination to the ESE. the outcrop of the Ben More thrust-plane can be traced for two and a half miles down the Oykell valley, whence it swings round the west slope of Sgonnan Mòr. From this point it extends southwards to Allt an Loin Dhuibh, south-east of Loch Borrolan, and round Cnoc na Glas Choille to the base of the Cromalt Hills, where it is overlapped by the Moine thrust-plane (Fig. 13).

A remarkable structural feature of this district is the formation of outliers of the materials above the Ben More thrust-plane, from two to five miles west of its main outcrop. The accompanying section (Fig. 15) illustrates this peculiar structure.

At the western limit of the section the undisturbed Lewisian Gneiss (𝔄) is covered unconformably by the Cambrian quartzites, followed in normal sequence by fucoid-beds, serpulite-grit (all shown as a), and the basal dolomite of the Calcareous Series. Eastwards, for a short distance, the zones are repeated by reversed faults, which are truncated by a major thrust that has driven westwards the two lowest groups of dolomite and limestone.

Farther east, on Beinn an Fhuarain, east of the River Loanan and Loch Awe (Fig. 13), an outlier of materials above the Ben More thrust-plane rests upon displaced members of the Calcareous Series, and is separated from them by a dislocation with circular outcrop. In the core of the outlier there is a small development of Lewisian Gneiss with a basic dyke, overlain unconformably by Torridonian grits and sandstones (t). On the north-west face of the hill the basal quartzites

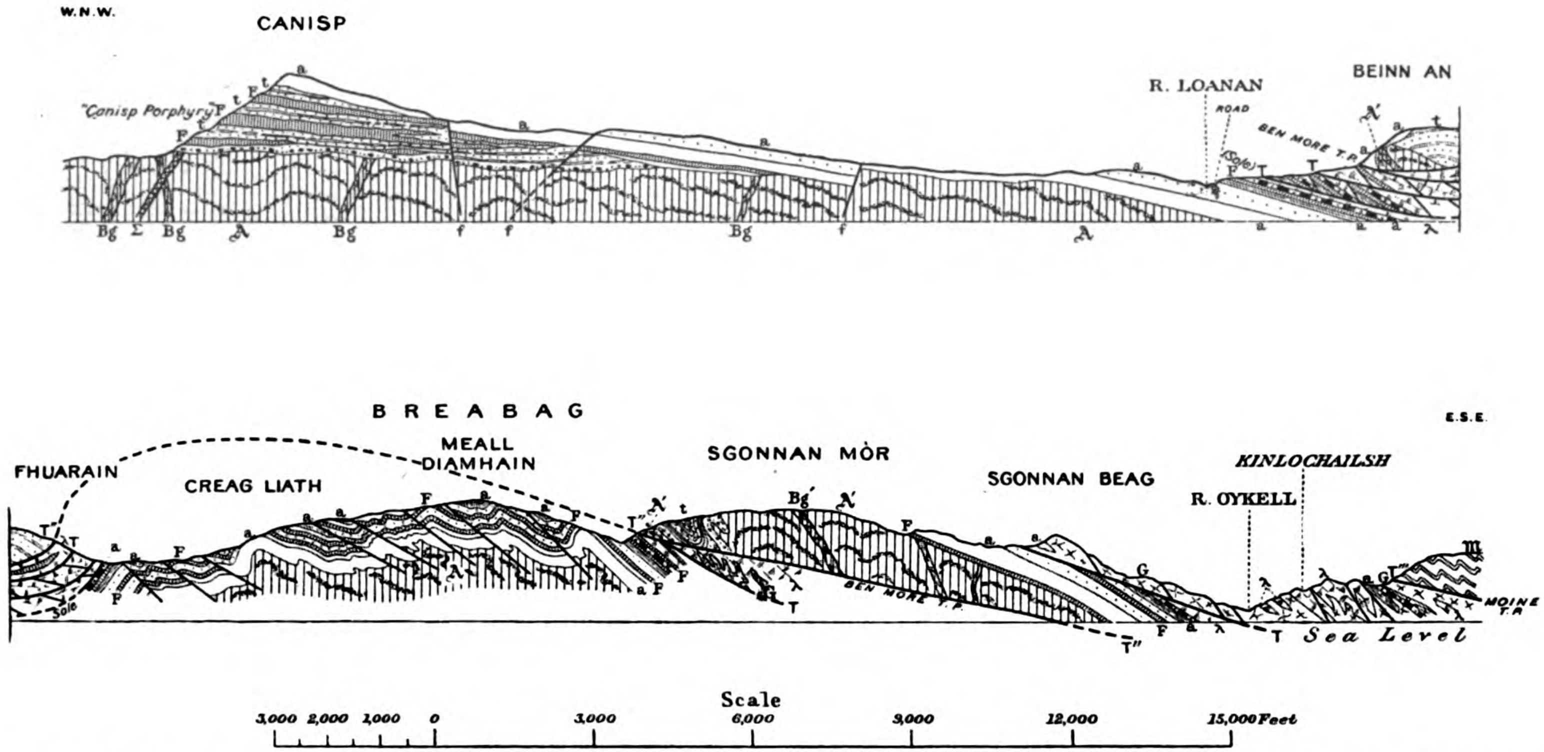


FIG. 15. Section from undisturbed foreland at Canisp past Kinlochailsh through Ben More and Moine Thrusts. 𝔄 Lewisian Gneiss with Bg Basic Dykes and Σ Ultra-basic Dyke (𝔄′ & Bg′, where thrust). t Torridonian. a Basal Quartzite, Pipe-rock, Fucoid-beds, and Serpulite-grit of Cambrian. λ Calcareous Series of Cambrian mostly marmorized. F Porphyrite Sills. G Syenite and Borolanite. 𝔪 Moine Schists. T and T.P Thrust-planes. T″ Ben More Thrust. T‴ Moine Thrust. f Faults. (*After 'N.W. Highland Memoir', Fig.* 36.)

occur in inverted order immediately above the thrust-plane, and pass transgressively across the gneiss and Torridon Sandstone, an example of the double unconformity of this zone on the older rocks. The Allt nan Uamh (Burn of the Caves) has carved a deep channel through the underlying calcareous rocks, and has isolated the outlier on Beinn an Fhuarain from the smaller outlier on Beinn nan Cnaimhseag on the north side of the stream. Along the north margin of the latter outlier the bare thrust-plane, in Eilean Dubh dolomite, is well displayed.

The broad dome of Breabag forms a compound anticline, consisting of quartzites, fucoid-beds, and serpulite-grit (all lettered a, Fig. 15), with sills of alkaline igneous rocks (F), repeated by reversed faults. East of Breabag the main outcrop of the Ben More Thrust appears on the west slope of Sgonnan Mòr, where it brings forward a slice of Lewisian Gneiss with inverted Torridonian strata.

Moine Thrust. The striking feature of this line of disruption in the Assynt district, as previously indicated, is the great overlap of the Eastern Schists above the plane. East of the Assynt mountains the general trend of the Moine Thrust is towards the south till it reaches Allt Eileag, a tributary of the Oykell River. From this point it runs westward for six miles along the northern base of the Cromalt Hills to the cliff by the road-side about a mile SSW. of the hamlet of Knockan (southern margin of Fig. 13). In its westward course it passes transgressively across the rocks above the Ben More thrust-plane and the piled-up Cambrian dolomites and limestones in advance of that disruption, till the Eastern Schists rest directly upon the undisturbed Cambrian strata at Knockan.

About half a mile east of the Knockan cliff the observer may walk on the Moine thrust-plane, laid bare in the bed of a tributary of Amhain a' Chnocain (Pl. XII, 1). Its pavement is composed of heaped-up masses of Cambrian dolomite and limestone dipping to the east, each successive bed being truncated by the Moine Thrust. The Eastern Schists, forming the cliff on the right bank of the stream, dip south-south-west, south, and south-south-east away from the plane. This great discordance, produced by earth movements on a stupendous scale, resembles the boundary line between two unconformable rock formations.

The accompanying horizontal section (Fig. 16) shows the relations of the strata at the Knockan cliff. The undisturbed Lewisian Gneiss (𝔄) appears at Loch Sionascaig (Skinaskink) overlain by a great pile of Torridon Sandstone (Bb) forming Cùl Mòr, the summit of which is capped by an outlier of basal quartzite. Descending the slope and passing eastwards to the Knockan cliff we find the basal quartzites, the pipe-rock zones, fucoid-beds, serpulite-grit (all lettered a), and a

PLATE XII

1. Stream section 1 m. SSW. of Knockan. Schuppen of Cambrian dolomitic limestone on left bank pass beneath cliff of Moine schist on right.

2. Knockan cliff. Hammer stands on white Cambrian marble. Lewisian gneiss follows above black recess. Moine schist forms overhanging cliff.

EXPOSURES OF MOINE THRUST-PLANE

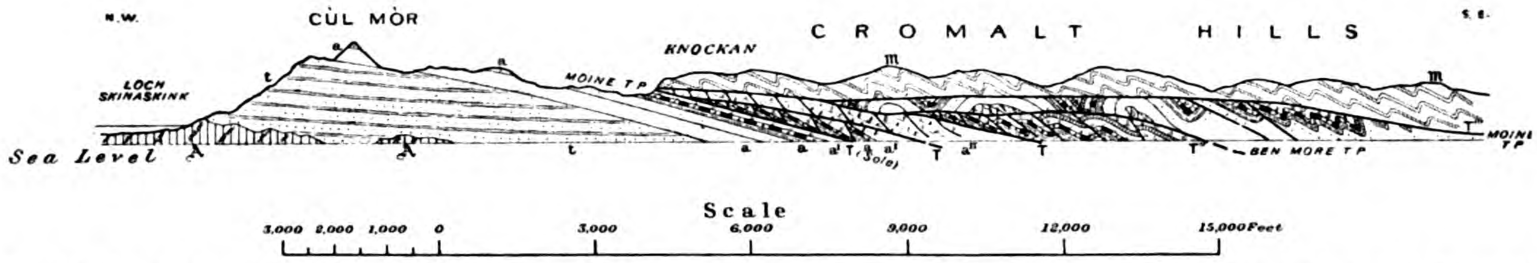


FIG. 16. Section showing overlap of Moine Thrust at Knockan on south margin of Fig. 13. 𝔄 Lewisian Gneiss. t Applecross Group of Torridonian. a Basal Quartzite, Pipe-rock, Fucoid-beds, and Serpulite-grit of Cambrian. a^{I-II} Groups of Calcareous Series of Cambrian. 𝔪 Moine Schists. T and T.P Thrust-planes. T″ Ben More Thrust. T‴ Moine Thrust. (*After 'N.W. Highland Memoir', Fig.* 40; Loch Skinaskink now written Loch Sionascaig.)

small portion of the basal dolomite (a[1]) of the Ghrudaidh Group, all in natural sequence, and dipping south-east at angles varying from 9° to 12°. *Here a few feet of thrust and crushed marble are exposed between the undisturbed strata beneath and the overlying Eastern Schists* (Pl. XII, 2), *but, at the southern end of the Knockan cliff, the Moine Thrust has overlapped the crushed marble, and the Eastern Schists rest directly on the Ghrudaidh dolomite.* The passage from the undisturbed Cambrian beds below to the overlying Eastern Schists appears to be quite conformable, as the strata dip in the same direction and nearly at the same angle. In the prolonged controversy relating to the geological structure of the North-West Highlands this section was regarded as furnishing conclusive evidence of a conformable sequence, but the tracing of the boundary line from the north coast of Sutherland and southwards to Skye has proved it to be entirely deceptive.[1]

HIGHLAND BORDER ROCKS REFERRED TO UPPER CAMBRIAN AND LOWER ORDOVICIAN

The Highland Border Rocks, which, in virtue of the fossils found in them, are provisionally regarded as of Upper Cambrian and Lower Ordovician age, form a narrow interrupted belt, exposed at intervals along the line of the Highland Boundary Fault from Garron Point, north of Stonehaven, to North Glen Sannox in Arran. In this belt the types of sedimentation and the assemblage of organic remains differ widely from those met with in the Cambrian rocks in the North-West Highlands. These variations will appear in the following descriptions of this series where best developed along the Highland Border.

Before the discovery of organic remains in these strata they were supposed by Nicol,[2] and by Murchison and A. Geikie[3] to be altered representatives of Silurian strata in the Southern Uplands, though linked with the metamorphic rocks of the Highlands. In 1863 Nicol[4] described the well-known section in the quarry, east of the Pass of Leny at Callander, where black shales, limestones, and grey and red shales are exposed, zones which are now regarded as of special importance in this series. The unaltered character of the beds at that locality evidently impressed him, as he refers to them in the

[1] A colour-printed map of the Assynt District, containing a series of colour-printed, horizontal sections drawn by Dr. Peach, has been issued by the Geological Survey (1923), as well as a 'Guide to the Geological Model of the Assynt Mountains' (1914).
[2] *Guide to the Geology of Scotland*, Edin. (1844), pp. 139, 249.
[3] *First Sketch of a New Geological Map of Scotland. With Explanatory Notes*, Edin. (1861), p. 11; see also *Geological Map of Scotland*, by A. Geikie (1876).
[4] 'On the Geological Structure of the Southern Grampians', *Quart. Jour. Geol. Soc.*, vol. xix (1863), pp. 186–7.

following terms: 'both the texture and colour of the limestone, and the black carbonaceous-looking shales associated with it, remind us rather of the Carboniferous formation than of a primary deposit'.

In his Presidential Address to the Geological Society, in 1891, Sir A. Geikie[1] published a table showing, *in the apparent descending order*, the various subdivisions of the metamorphic rocks which had been recognized by the Geological Survey in the Highlands of Perthshire. The black shales and flags, with lenticular bands of limestone, seen against the great Highland Boundary Fault at Callander, are placed at the base of the succession.

During the progress of the Geological Survey along the Highland Border between 1893 and 1899,[2] evidence was obtained in Forfarshire and Kincardineshire by G. Barrow, in the Aberfoyle district by J. R. Dakyns and C. T. Clough, and in North Arran by W. Gunn, which threw some light on the probable stratigraphical horizon of these rocks. Sediments were mapped consisting of jaspers, cherts with radiolaria, and black shales, underlain by green igneous rocks partly schistose but still showing pillow-structure in places, and overlain by grits and cleaved shales with lenticular patches of limestone. The resemblance of this sequence of igneous and sedimentary materials to the Arenig volcanic rocks, radiolarian cherts, black shales and overlying sediments in the Southern Uplands was at once recognized, and led to the provisional correlation of the Highland Border Rocks with the Silurian (Ordovician) strata in the Southern Uplands. In the official reports admission was frankly made that it was extremely difficult to draw a boundary line, in the Aberfoyle district and in Arran, between the supposed Silurian rocks to the south and the Highland slates and grits to the north.

In his important contribution to Highland geology, published in 1908, P. Macnair[3] described the general structure, succession, and lithological characters of the rocks seen at Callander, the Pass of Leny, and the Kelty Water on the Highland Border. He concludes that 'the structure, age, and relationships of this marginal belt of rocks seen in Highland Perthshire must still remain an open question. . . . In the meantime, until further evidence is forthcoming, we are inclined to look upon this marginal belt of grits and phyllites, with the less altered beds of shale and limestone, as forming one stratigraphical group, conformably underlying, and older than, the shales and limestones of the interior.'

[1] Ibid., vol. xlvii (1891), *Proc.*, p. 74.

[2] See Annual Reports of the Geological Survey for 1893, Appendix E, p. 266; for 1895, p. 25; for 1896, p. 27. See also 'Summary of Progress for 1899', *Mem. Geol. Surv.* (1900), p. 68.

[3] *The Geology and Scenery of the Grampians*, Glasg. (1908), pp. 48, 49.

In 1910, in his Presidential Address to the Geological Society of Glasgow, Professor J. W. Gregory[1] referred to this series in the following terms: 'It seems to me that they are either the uppermost part of the series which includes the Aberfoyle slates and grits, or a younger series, separated from the Aberfoyle series by a still doubtful unconformity and by the absence of cherts from the Aberfoyle series.' He also stated that the sections in the tunnel of the Loch Katrine aqueduct, four and a half miles south-west of Aberfoyle, show that the Highland Border Series is separated from the rocks to the north by an overthrust fault.[2]

An important advance was made by Dr. R. Campbell,[3] when, in 1911, he announced the discovery of brachiopods and specimens of a phyllocarid crustacean in black, cherty shales associated with the green, schistose igneous rocks north of Stonehaven.

Further striking evidence was obtained in the Aberfoyle district by Professor Jehu,[4] who, in 1912, found brachiopods, phyllocarid crustaceans, and graptolites in the Chert and Black Shale Series of that region.

Rocks, Distribution, and Geological Structure.

The sequence of these Highland Border Rocks was first described by Mr. G. Barrow,[5] in Forfarshire and Kincardineshire. In view of the importance of his suggestions regarding the tectonics of that area special reference is here made to his researches.

North Esk Area. These rocks form three narrow lenticular strips *which intervene between the Highland schists on the north-west and the boundary fault that truncates the Lower Old Red Sandstone on the south-east.* The largest strip, about twenty miles long and about three quarters of a mile broad in the North Esk section, extends from Cortachy in Forfarshire to about a mile beyond Clattering Bridge in Kincardineshire. The second runs from a point near Drumtochty Castle north-eastwards for six miles, and the third for about a mile ENE. of Elfhill (Geol. Surv. One-inch Map of Scotland, Sheets 57 and 66).

The rocks are arranged in two divisions, (1) the Jasper and Green-

[1] 'The Problems of the South-Western Highlands', *Trans. Geol. Soc. Glasg.*, vol. xiv, part i (1910), p. 16.

[2] Loc. cit., p. 15.

[3] 'Preliminary Note on the Geology of South-Eastern Kincardineshire', *Geol. Mag.*, Dec. V, vol. viii (1911), p. 63.

[4] *Nature*, vol. lxxxix (1912), p. 347; *Rep. Brit. Assoc.* (1912), p. 463.

[5] 'On the Occurrence of Silurian (?) Rocks in Forfarshire and Kincardineshire along the Eastern Border of the Highlands', *Quart. Jour. Geol. Soc.*, vol. lvii (1901), p. 328.

Rock Series overlain unconformably by (2) the Margie[1] Series. The following zones are met with in descending order:

Margie Series

(5) Grey shale.
(4) Pebbly limestone, lenticular, one to five feet thick; quarried at all known outcrops.
(3) Dark, carbonaceous, grey, chocolate-coloured, and white shales; about twenty feet thick.
(2) Pebbly grits, with carbonate of iron cement, becoming coarse towards the base; about 120 feet thick in the North Esk section.
(1) Green conglomerate, occurring locally, about thirty feet thick in the North Esk section.

Jasper and Green-Rock Series

(4) Fine grit with microcline pebbles.
(3) Fine shale, always cleaved, with a pseudo-crystalline aspect.
(2) Jasper (altered radiolarian chert ?), six feet thick in the North Esk section; at certain localities it seems to be replaced by jaspery phyllite.
(1) Green rocks, mainly lenticular sills of ophitic dolerite, though some lava-flows may also be present; upper part only visible.

The North Esk furnishes the best exposures of both divisions, and the section given by Barrow (Fig. 17) shows the relations of the strata in that district.

The members of the Jasper and Green-Rock Series form a compound anticline, bounded by the Margie beds on the north-west and south-east sides. The jaspers and phyllites are repeatedly infolded in the Green-Rock Series, and owing to the rapid plication of the zones, no rock much below the horizon of the jasper is laid bare.

On the south-east side of the compound anticline the members of the Jasper and Green-Rock Series are thrust over the Margie beds, which are repeated by various folds. The basal conglomerate of the latter series is not visible in this part of the section. The dominant strata are sandstones or grits, weathering pale brown, but white in fresh fracture. The pebbles of quartz and felspar lie in a matrix of carbonates of iron and lime which effervesces freely with acid. The felspar consists mainly of oligoclase, which is abundant in the adjacent Highland schists and may have been derived from that source; similarly the quartz may have been obtained from the quartz-segregations in the schists to the north. The grits are associated with white, grey, and chocolate-coloured shales, containing original clastic micas, the presence of which distinguishes them from the Highland slates. This younger series is truncated by the Highland Boundary

[1] This series receives its name from the Margie Burn, two miles south-west of the North Esk River, where the beds were first identified by G. Barrow.

Fault, which brings them into conjunction with the Lintrathen porphyrite, associated with the Lower Old Red Sandstone (see Fig. 17).

On the north-west side of the compound anticline, the jaspers and green-rocks are succeeded by a coarse, green conglomerate at the base of the Margie Series. It is composed of the underlying igneous materials with small fragments of red jasper. The original unconformable junction has here been slightly disturbed by a minor thrust, and the conglomerate is traversed by small planes of movement (see Fig. 17), but the unconformity is visible in other exposures. The abundance of pebbles and blocks of the underlying green igneous materials with fragments of jasper in the conglomerate shows that the Margie beds must be of later date. Next in order come the grits, followed by chocolate-coloured and dark-grey shales, the latter containing some carbonaceous material. Northward the band of pebbly limestone is visible in the quarry where it was formerly worked, associated with a thin band of dark shale. Farther north the limestone is repeated by folding with a persistent dip to the north-west and is succeeded by the shales in inverted order. At this point in the section the Highland slates with a different grade of metamorphism have been driven over the Margie beds by a major thrust. It is maintained that here 'there is no true upward succession from the sheared Margie shale with its original clastic micas to the finely crystalline slate in which no trace of clastic mica has been found anywhere in this district'.

Barrow gives the following summary of his main conclusions regarding these remarkable rocks on the Highland Border:[1]

'(1) They may be arranged in two divisions (*a*) the Jasper and Green-Rock Series, and (*b*) the Margie Series. The former is most probably of Arenig age, and the latter is of later date, though undoubtedly of pre-Old Red Sandstone age.

(2) Both groups of rock have been much deformed, the shearing being most persistent along the junction of the Highland rocks with the northern margins of the supposed Silurian rocks.

(3) The appearance of an upward succession at this line of junction is always deceptive, the boundary being marked by a great line of displacement or overthrust which has been proved to extend for many miles.

(4) The apparent passage from the non-crystalline newer rocks (Silurian ?) into the Highland schistose series is equally deceptive.

(5) The crushing accompanying this thrust never extends more than a few yards into the Highland Series, owing to the induration of the rocks of that series by previous metamorphism.

(6) The position of the major thrust truncating the so-called Silurian

[1] Loc. cit., pp. 342–3.

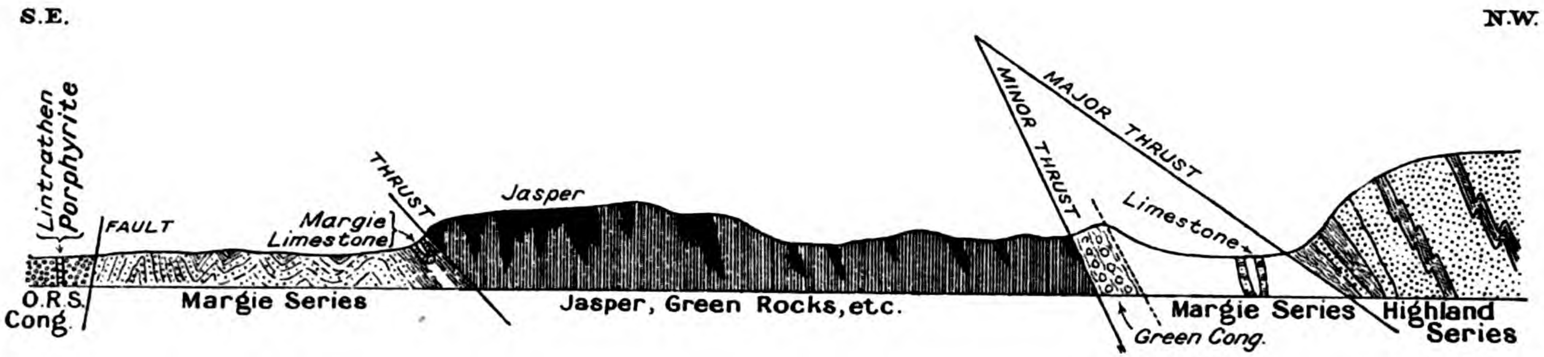


FIG. 17. Diagrammatic section across Highland Border Rocks near North Esk. (*After G. Barrow, 'Quart. Journ. Geol. Soc.', vol.* lvii, *p.* 330.)

rocks on the north and that of the later great boundary-fault skirting the Old Red Sandstone have been determined by the outer limit of the great aureole of crystallization of which the South-eastern Highlands form a part. The harder crystalline schists of the north-west have snapped off, under the influence of enormous pressure, from the softer portions now covered by newer rocks to the south-east.

(7) Though the rocks have been much sheared they have not been changed into crystalline schists. In particular, the sheared basic igneous rocks are never altered to hornblende-schists.'

Stonehaven Area. Dr. R. Campbell mapped a narrow strip of Highland Border Rocks on the coast near Stonehaven from a point on the foreshore opposite St. Mary's Chapel, Cowie, northwards to Garron Point. In this area these rocks occur to the *south of the great Highland Boundary Fault*. The following details regarding the results of his work are taken from his paper published by the Royal Society of Edinburgh.[1]

The dominant type consists of sheared and folded green igneous rocks, merging into chlorite-schists. Vesicular and 'pillowy' structures are still preserved in them, thereby suggesting that they are of volcanic origin. When the least altered specimens are examined under the microscope they present the characteristics of typical spilitic lavas. The coarsely crystalline types, presumably intrusive, described by Barrow from the North Esk area, have not been found in the Stonehaven sections.

These igneous rocks are associated with cherts, jaspers, and black cherty shales, rich in iron oxides, which occur chiefly as intercalations between the flows and also in lenticular masses. In 1909 Dr. Campbell found a linguloid shell, a bivalve phyllocarid crustacean, and a worm tube in the black cherty shales. In view of the importance of this discovery, the aid of Mr. Tait of the Geological Survey was obtained, and the fossils collected by him were submitted to Dr. B. N. Peach, who supplied the following note:[2]

'The collection includes several specimens of hingeless brachiopods belonging to the genera *Lingulella*, *Obolella*, *Acrotreta*, *Linnarssonia*, and *Siphonotreta*; a few specimens of a bivalve phyllocarid allied to *Caryocaris* and *Lingulocaris*; cases of a tubicolar worm, the structure of the tubes being like that of the modern *Ditrupa*.

'Without further study it may be premature to express a definite opinion about the horizon of these fossils. The genera represented are most commonly found in the lowest division of the Lower Silurian (Ordovician) system and the Upper Cambrian. The absence of graptolites, however, suggests that they may belong to the latter rather than to the Lower Silurian.'

[1] 'The Geology of South-Eastern Kincardineshire', *Trans. Roy. Soc. Edin.*, vol. xlviii, part iv (1913), p. 923.
[2] Loc. cit., p. 927.

A selection of the fossils was sent to Dr. Walcott of the Smithsonian Institution, Washington, for determination, who kindly furnished the following report:[1]

'I have just carefully examined the specimens, and am inclined to agree with Dr. Peach that the fauna indicated is Upper Cambrian. The larger brachiopod appears to be *Obolus* (*Bröggeria*) *salteri*, Hall, and slender shells conform closely to *Hyolithellus*. One fragment indicates the presence of a Phyllopod.

'There is also a small species of *Lingulella* that may be compared to *Lingulella nicholsoni*.'

Along their northern boundary at Garron Point the Upper Cambrian rocks are separated from the Highland schists (Dalradian) by an overthrust fault, which can be traced from that headland south-west to Craigeven Bay (Fig. 18). The line of fracture is indicated by a dolomitic fault-rock with a maximum thickness of forty feet.

These Upper Cambrian rocks are overlain unconformably at Ruthery Head by the breccia marking the base of the Downtonian Series.

Aberfoyle Area. The belt of Highland Border Rocks, extending from Gualann, a hill six miles south-west of Aberfoyle, to a point beyond Upper Dounans about a mile north-east of that village, was mapped by Professor T. J. Jehu. The paper, containing the results of the investigations connected with this research, by Professor Jehu and Dr. Campbell, was published in 1917 in the Transactions of the Royal Society of Edinburgh.[2]

While prosecuting work in the field Professor Jehu had the great advantage of consulting the maps and notes made by C. T. Clough in the course of the survey of that area (Geol. Surv. One-inch Map of Scotland, Sheet 38), and of discussing with him the problems involved. The main boundary lines in Professor Jehu's published map coincide generally with those previously drawn by Clough. The paper contains important additions to our knowledge bearing on the palaeontology, petrology, and tectonics of these rocks, from which the following details are taken.

North-east of Aberfoyle, the belt is only about 100 yards wide and it disappears to the east of the old limestone quarry at Upper Dounans. South-westwards the width is variable, the maximum of half a mile being reached north of Gualann, where these rocks are covered unconformably by the Upper Old Red Sandstone. On the south-east side the belt is truncated by the Highland Boundary Fault which

[1] Extract from Dr. Walcott's Letter, dated 8th February 1911, sent to Dr. Horne.

[2] 'The Highland Border Rocks of the Aberfoyle District', *Trans. Roy. Soc. Edin.*, vol. lii, part i (1917), p. 175.

brings the rocks in contact with the Lower Old Red Sandstone. On the north-west side it appears to be everywhere separated from the Leny Grits (Dalradian) by a dislocation inclined to the north-west at high angles.

The Highland Border Rocks include (*a*) a Lower Series, composed of chert, cherty shales, black and grey shales, and mudstones passing downwards into, and interbedded with, spilitic lavas; and (*b*) an Upper Series, termed the Margie Series, resting unconformably on the Lower Series, composed of grits, shales, and limestones with a remarkable breccia at its base. The intrusive rocks associated with (*a*) consist of albite-diabase, albite-gabbro, and serpentine.

(i) *The Lower or Black Shale and Chert Series.* The spilitic lavas, which are the lowest visible members of the series, are green, compact, occasionally vesicular rocks, that sometimes show a well-marked flaser structure. In fresh specimens the felspar is albite, but the ferromagnesian minerals are decomposed, and are now represented by secondary chlorite and carbonates. They are overlain by fine-grained, black shales, grey cherty shales, and mudstones. Fossils have been obtained from the grey muddy cherts and cherty shales, the fossiliferous bands varying from one to four inches in thickness. The pure cherts are rich in radiolaria; the muddy cherts are characterized by the scarcity of radiolaria, the abundance of needles of rutile, and the occasional presence of clastic grains. The remains of graptolites, which were determined by Dr. Gertrude L. Elles, are poorly preserved. The best fossiliferous locality is on the south-east side of the Bofrishlie Burn, about 400 yards north-west of Arndrum, and about two miles south-west of Aberfoyle village.

The following list of fossils has been obtained from the cherty beds:

I. *Radiolaria*, species indeterminate.

II. *Graptolitoidea.*

Forms belonging to the family of *Diplograptidae*—
Trigonograptus or *Cryptograptus.*
A form of the family *Retiolitidae.*

III. *Brachiopoda.*

Obolus, species indeterminate.
Lingulella aff. *ferruginea* Salter
,, aff. *nicholsoni* Callaway
Acrothele (*Obolella*) *maculata* Salter
,, (*Redlichella*) *granulata* (Linn.)
,, aff. *coriaceae* (Linn.)
Acrotreta nicholsoni Dav.
,, *socialis* von Seebach
,, aff. *sabrinae* Callaway

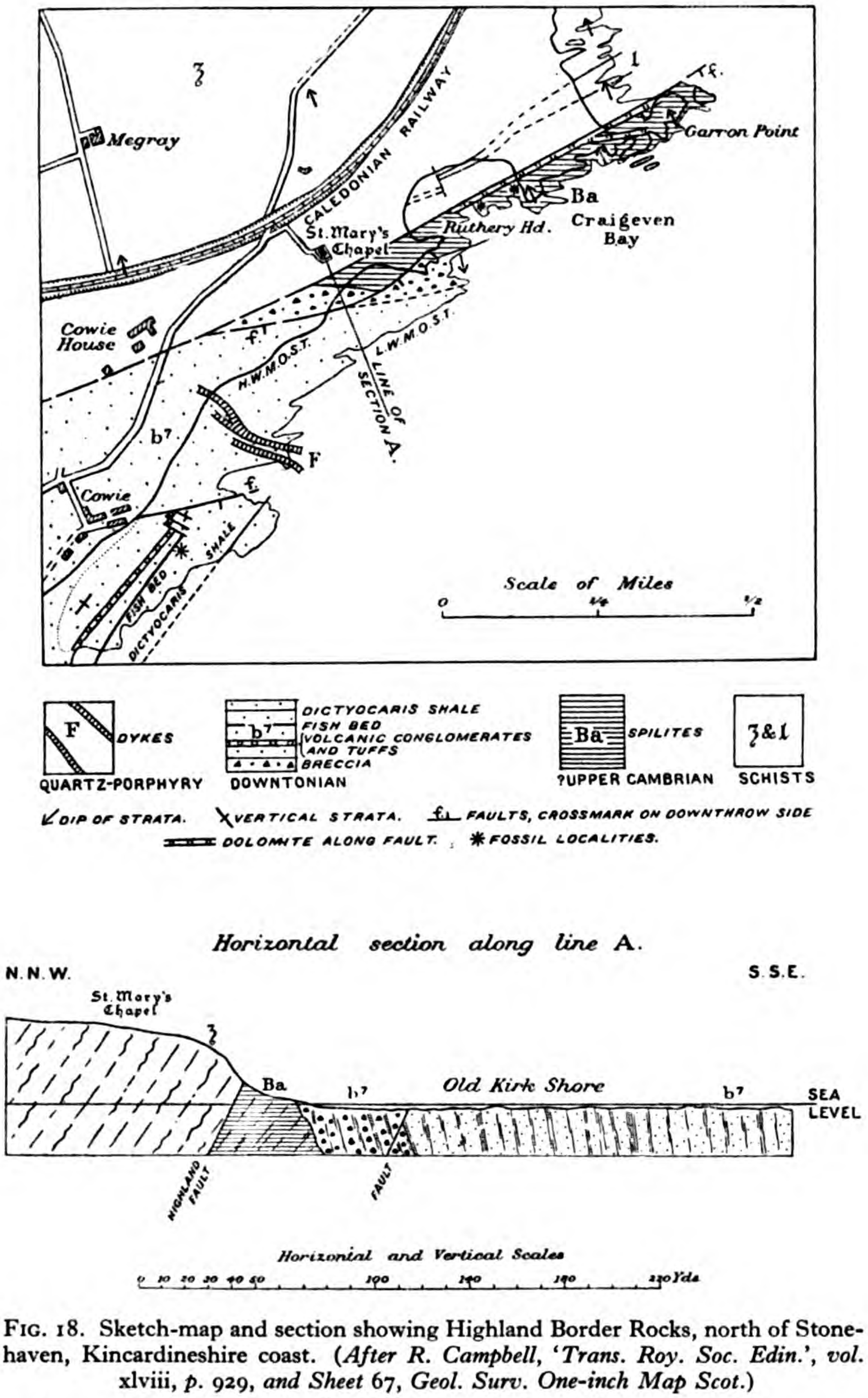


FIG. 18. Sketch-map and section showing Highland Border Rocks, north of Stonehaven, Kincardineshire coast. (*After R. Campbell, 'Trans. Roy. Soc. Edin.', vol.* xlviii, *p.* 929, *and Sheet* 67, *Geol. Surv. One-inch Map Scot.*)

III. *Brachiopoda*—continued

Siphontreta aff. *micula* M'Coy

,, aff. *scotica* Dav.

? *Schizambon*

IV. *Phyllocarida* (*Leptostraca*).

Modiolocaris dakynsi Peach

Other forms allied to *Lingulocaris* and to *Peltocaris*

V. *Incertae sedis*.

Various remains of Arthropods, &c.

(ii) *The Upper or Margie Series*. The basement breccia contains large angular fragments of cherty shales resembling some of the bands in the underlying series. The other ingredients consist of vesicular palagonite, quartz, and pieces of cherty mudstone and shale. Palagonite, however, is the dominant constituent. The vesicles of this material are mostly filled with green chlorite, and the glass has undergone complete alteration. In some localities pieces of spilitic lava with well-preserved felspars occur in the basal breccia.

The overlying grits are composed mainly of quartz, felspars, and micas, in association with zircon and tourmaline. Quartz, however, is the dominant constituent, but felspar is nearly as abundant in some of the arkose varieties. The quartz is mostly of the granitic type with inclusions of fluid cavities and rutile needles. The felspars include microcline, orthoclase, perthite, and plagioclase; they are usually well preserved, but the orthoclases sometimes show alteration into sericite. Clastic muscovite is prevalent with zircon and tourmaline. Pieces of black shale and fragments of cherty shale derived from the underlying series are of common occurrence in these beds. Greyish-green shales and mudstones are associated with the grits.

The limestone, if it is to be regarded as the equivalent of the Margie limestone, deserves special mention as it has yielded fossils. The rock is crystalline, much brecciated, and veined with calcite. It is exposed in the quarry near Upper Dounans about a mile north-east of the village of Aberfoyle. The accompanying section (Fig. 19) shows its relations to the adjacent rocks.

On the south-east side the limestone is truncated by the Highland Boundary Fault which brings it in contact with the Lower Old Red Sandstone of the Menteith Hills. On the north-west side it is cut off by a line of movement from a band of serpentine, which is separated by a fault from the Margie beds and the black shale and chert. The latter beds are truncated in turn by a thrust that brings forward the Leny Grits (Dalradian). Though the Upper Dounans limestone is involved in the lines of movement accompanying the Highland Boundary Fault, it presumably belongs to the Margie Series, and probably corresponds with the Kilmahog limestone of Callander, and with the Margie limestone of Forfarshire.

Plates of crinoids have been recognized in the Upper Dounans limestone—a determination confirmed by Dr. F. A. Bather. Fragments of calcareous *Algae* and rounded bodies that are apparently *Foraminifera* have been observed by Dr. G. J. Hinde.

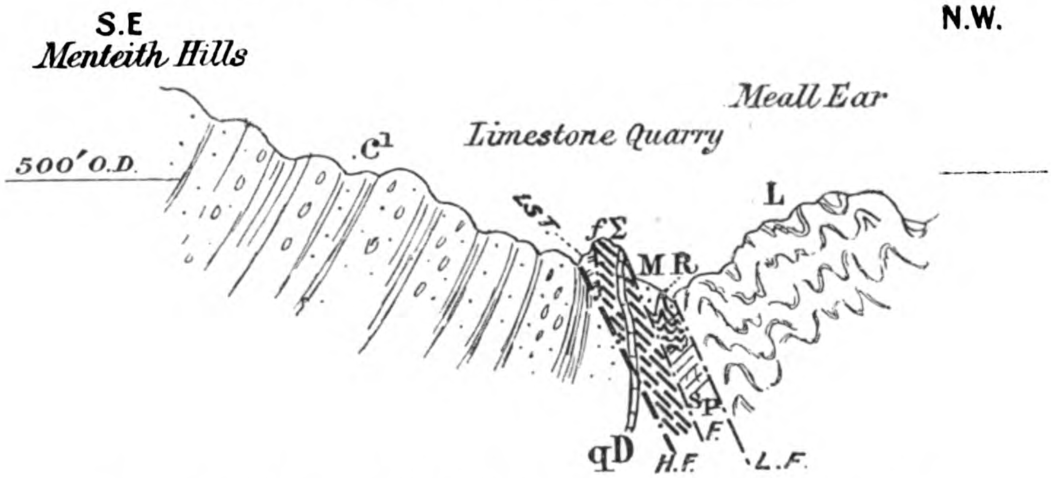


FIG. 19. Section across Highland Border Rocks, east of Aberfoyle. (*After T. J. Jehu and R. Campbell, 'Trans. Roy. Soc. Edin.', vol.* lii, *p.* 207.)

qD, quartz-dolerite; C^1, Lower Old Red Sandstone; M, Margie Series; Lst., Aberfoyle Limestone; R, Shale and Chert Series; Sp, Spilites; Σ, Serpentine Complex; L, Leny Grits; H.F., Highland Fault; L.F., Leny Fault.

The value of the palaeontological evidence in fixing the age of the Highland Border Rocks is referred to in the following terms:

'The assemblage of fossils obtained from the cherts is strongly suggestive of an Upper Cambrian or Lower Ordovician horizon. The brachiopods and phyllocarid crustaceans are represented by genera and species which are characteristic of Upper Cambrian and Lower Ordovician Rocks elsewhere. A few of the brachiopods have been noted hitherto only from the Middle Cambrian. The graptolites, on the other hand, point to an Ordovician horizon. Taking the evidence from the fossils as a whole, we are justified in fixing the horizon of the Lower or Black Shale and Chert Series as Upper Cambrian, or the Passage Beds between the Cambrian and Ordovician. . . . It follows that the Upper or Margie Series, which is unconformable to the Lower Series, must belong at any rate to Lower Ordovician times.' (Op. cit., pp. 193–4.)

The serpentine-gabbro complex is a prominent feature of the igneous intrusions associated with the Highland Border Rocks. It has been traced at intervals along the north side of the Highland Boundary Fault between Gualann and the Upper Dounans limestone quarry.

It is supposed to have been derived from the magma which gave rise to the spilitic lavas of the Black Shale and Chert Series.

A notable feature of this tract of Highland Border Rocks is the occurrence in it of a belt of metamorphic rocks, composed of hornblende- and chlorite-schists with schists of sedimentary origin. The hornblende-schists are believed to represent metamorphosed, intrusive diabases and gabbros, and the chloritic schists deformed spilitic lavas. Banded quartz-schists are the dominant type of the sedimentary schists. From the presence of relics of garnet in them, it is inferred that these sediments were affected by an earlier contact metamorphism, produced by the intrusion of the diabases before the dynamic metamorphism of the belt.

A comparison is drawn between the Margie Grits and the Leny Grits (Dalradian) which lie to the north of the Highland Border Rocks. Most of the Leny Grits are charged with clastic muscovites and biotites. The quartz in them is mainly granitic; the felspars include microcline, perthite or orthoclase, and plagioclase. At Craigmore, where the rock becomes conglomeratic, microcline is almost the only felspar present. These constituents are associated with zircon, green and brown tourmaline, and iron ores. Rock fragments, including green mudstone, microcline-granite, microcline-pegmatite, spilite, jasper, and quartzite have been observed in the Leny Grits, but no schistose types. The constituents of both the Margie and Leny Grits are supposed to have been derived from an area of granitic rocks. The members of the Leny Grit Series exhibit on the whole a higher grade of metamorphism than the Highland Border Rocks. But it is maintained that the method adopted by G. Barrow in the North Esk area of distinguishing the Margie Series from the Highland rocks to the north, by the presence of clastic micas in the former and their absence in the latter, does not apply to the Aberfoyle district. Clastic micas occur in the Leny Grits (Dalradian) in contact with the Highland Border Rocks.

Jehu and Campbell give the following summary of the results of their researches :[1]

'1. The Highland Border Rocks in the district can be arranged in two divisions:—

(*a*) The Lower Series, consisting of cherts, cherty shales, and black shales overlying and in less measure interleaved with spilitic lavas, and associated with igneous intrusions and with a group of highly metamorphosed rocks of both igneous and sedimentary origin.

(*b*) The Upper or Margie Series, made up of grits, shales, and limestone, along with a remarkable basal breccia.

[1] Op. cit., pp. 208–9.

'2. The sediments of the Lower Series point to deposition in clear water near the verge of sedimentation, from which coarse terrigenous material was excluded and in which *Radiolaria* thrived; the lavas indicate submarine volcanic eruptions. The beds of the Upper Series are unconformable to the Lower Series, and their constituent materials are in part the result of the denudation of the Lower Series. The Margie grits and shales are due to the accumulation of comparatively coarse terrigenous material laid down on a slowly subsiding land area. The basement breccia affords evidence of recrudescence of volcanic activity at the beginning of Margie times.

'3. The Lower Series is either of Upper Cambrian age or belongs to the Passage Beds between the Cambrian and the Ordovician.

The Upper Series includes the fossiliferous limestone, and may be placed with confidence on a higher horizon in the Ordovician system.

'4. The igneous rocks, both lava-form and intrusive (including their metamorphosed representatives), which are associated with the Lower Series show certain affinities in mineralogical composition and in petrographical characters which lead to the conclusion that they have been derived from the same magma.

'5. The hornblendic and chloritic schists are the result of the dynamic metamorphism of hypabyssal and volcanic rocks along a belt where these rocks were subjected to intense shearing. The metamorphosed sediments were affected by contact metamorphism prior to the dynamic metamorphism of the belt.

'6. The whole belt of Highland Border Rocks is affected by lines of crushing and dislocation running in the direction of the general strike of the beds.

'7. The age of the Leny Grits still remains an open question, and one on which further investigation is needed. But it is clear that a line or lines of dislocation separate these from the Highland Border Series.'

Area between Gualann and Balmaha, Loch Lomond. The Highland Border Rocks north of Gualann are overlain unconformably by Upper Old Red Sandstone, which extends south-westwards for about three miles, on the north side of the Highland Boundary Fault, to Balmaha. North of the Pass of Balmaha they reappear in two lenticles, separated by Upper Old Red Sandstone, which have been described by A. L. Du Toit.[1] At Arrochymore Point in the northern patch, massive serpentine is seen to merge into a sheared and highly altered rock with carbonates and silicates of lime and magnesia, and ultimately into a foliated, red, ferruginous limestone or dolomite. This band is associated with grits belonging to the Margie Series.

In the southern lenticle extending north-eastwards from Balmaha for a mile to the northern slope of Conic Hill, a conglomerate occurs, composed of pebbles of serpentine and serpentinized gabbro lying in

[1] 'The Lower Old Red Sandstone Rocks of the Balmaha–Aberfoyle Region', *Trans. Edin. Geol. Soc.*, vol. viii, part iii (1905), p. 323.

a serpentinous matrix. The conglomerate is associated with breccias, sometimes serpentinous, sometimes dolomitic, calcareous or siliceous. Fragments of sedimentary material, including pale chert, occur in the breccias and the rock merges into grey coarse-grained grit, well seen in an old quarry on the ridge north of Balmaha. It is reasonable to infer that here we have a representative of the Margie basal conglomerate and grit so well developed between Gualann and Aberfoyle.

Arran Area. In North Glen Sannox, about six miles north of Brodick Castle, a strip of Highland Border Rocks was mapped by W. Gunn, of the Geological Survey (Geol. Surv. One-inch Map of Scotland, Sheet 21), and described by him in the Memoir on North Arran.[1] The belt varies from 100 to 400 yards in width and is about a mile and a half in length. The rocks consist mainly of volcanic and intrusive igneous materials with black shales and thin bands of chert, the whole series dipping to the ESE. at high angles. They are underlain and apparently overlain by ordinary schistose grits of the type commonly met with in the South-East Highlands.

The lavas are dull-green, fine-grained rocks which have undergone much deformation and are now in the condition of epidiorite. In some localities they are highly schistose. Pillow-structure is well developed in some of the volcanic rocks, the chilled margins of the pillows and the concentric arrangement of the vesicles being marked features. Thin lenticular bands of agglomerate composed of angular fragments of fine-grained lava also occur. The black shales are highly contorted, merging in places into phyllites, and the cherts have been granulitized. The sediments and associated lavas may be regarded as the equivalents of the Lower or Black Shale and Chert Series and volcanic rocks of Aberfoyle, North Esk, and Stonehaven. The relation of the Highland Border Rocks in Arran to the Highland schistose grits flanking them on either side has not been definitely ascertained.

Conclusions regarding the Highland Border Rocks.

Much research remains to be done regarding the fossiliferous Highland Border Rocks, but certain conclusions may justly be drawn from the work already accomplished.

The evidence proves that the rocks are divisible into two series: (1) a Lower or Black Shale and Chert Series with volcanic and intrusive igneous rocks; (2) an Upper or Margie Series, separated from the Lower by a marked unconformity. The Lower Series, consisting of spilitic lavas and clear-sea deposits, which include radiolarian cherts, cherty shales, and black shales, have yielded fossils at Garron

[1] 'The Geology of North Arran, South Bute, and the Cumbraes', *Mem. Geol. Surv.* (1903), p. 18; see also 'Geology of Arran', *Mem. Geol. Surv.* (1928), pp. 23–8.

Point, Stonehaven, and in the Aberfoyle belt. These fossils indicate that the deposits must be of late Cambrian or early Ordovician age.

The Upper or Margie Series is composed mainly of coarse terrigenous sediments, the basement beds of which contain abundant fragments of all members of the Lower Series, including the volcanic and intrusive igneous rocks. They are undoubtedly of younger date and presumably of Ordovician age. There is strong presumptive evidence that the Upper Dounans limestone, near Aberfoyle, yielding crinoid ossicles, calcareous *Algae*, and rounded bodies apparently *Foraminifera*, is the equivalent of the Margie limestone, though it is detached from the other Margie sediments along the Highland Boundary Fault. The presence of numerous fragments of palagonite in the basement beds indicates a recrudescence of volcanic activity at the beginning of Margie time. The pebbles of quartz and felspar in the Margie Grits in the North Esk area are supposed to have been derived from the Highland schists, but in the Aberfoyle region from an area of granitic rocks.

Both the Upper and Lower Series have been subjected to dynamic movement with local development of flaser structure, but the grade of metamorphism is low except along a narrow belt south-west of Aberfoyle.

In the North Esk and Aberfoyle regions the Highland Border Rocks are separated from the schistose grits and slates (Dalradian) to the north-west by steep disruption planes or thrusts, dipping towards the north-west, which appear on the maps as straight lines unaffected by the contours of the country. In this respect they differ from the great overthrusts in the North-West Highlands which are usually inclined at gentle angles.

The evidence furnished by the two series of Highland Border Rocks closely resembles that found in the Ballantrae-Girvan area, in the Southern Uplands. In that region the Arenig volcanic and intrusive igneous rocks, radiolarian cherts, and graptolite shales are covered unconformably by the Kirkland and Benan conglomerate, associated with mudstones, shales, and the fossiliferous Stinchar limestone of Llandeilo age. Dr. Peach suggests that the Margie limestone may be the equivalent of the Stinchar limestone. This correlation, however, cannot be regarded as proved. Following a suggestion of Professor Lapworth, he stated in his Presidential Address[1] to the Geological Section of the British Association at the Dundee meeting, that Upper Cambrian strata may yet be found in the Girvan area. No palaeontological evidence in support of this view has so far been obtained.

[1] *Rep. Brit. Assoc., Trans. Sec. C* (1912), p. 6.

V

HIGHLAND METAMORPHIC ROCKS

MOINE SERIES (EASTERN SCHISTS)

THE early observations of Macculloch[1] relating to the superposition of the eastern gneisses and schists to the quartz-limestone series (Cambrian) of West Sutherland were confirmed by Hay Cunningham,[2] who recorded the occurrence of an 'Upper Gneiss' resting upon the quartzites and limestones.

The apparent ascending succession from the quartzites and limestones, yielding fossils supposed to be of Silurian age, into the overlying gneissose flagstones, led Murchison and A. Geikie[3] to regard the Eastern Schists as metamorphosed representatives of strata belonging to the same system. Murchison called attention to the divergence in strike and the difference in lithological characters between the hornblendic and micaceous gneisses in the west (Lewisian) and the siliceous flagstones and mica-schists of the Eastern Schists.

Nicol,[4] as previously indicated, contended that the Eastern Schists are not younger than the fossiliferous quartzites and limestones, but belong to the great series of gneisses covered unconformably by the Torridon Sandstone. He was in error, however, in referring to the outliers of red conglomerate[5] in the Moine area east of the Kyle of Tongue as proof of the true succession of the rock formations in the north of Sutherland. He refers to these outliers in the following terms:

'The conclusion seems therefore irresistible that these Tongue conglomerates are identical in age, as they are in mineral character and composition, with the red conglomerates and sandstones of the west coast [Torridonian]. This identity is confirmed by the occurrence of the overlying quartzite on Cnoc Craggie [Creagach], near Loch Laoghal. The greater part of the hill consists of the conglomerate overlain on the south side by the quartzite in thick irregular beds. The preservation of these interesting fragments seems due to the great syenite eruption of Ben

[1] *A Description of the Western Islands of Scotland*, 3 vols., Lond., 1819, vol. ii, pp. 510, 511.

[2] 'Geognostical Account of the County of Sutherland', *Trans. Highland and Agric. Soc.*, vol. xiii, and n.s., vol. vii (1841), pp. 99, 100.

[3] 'On the Altered Rocks of the Western Islands of Scotland, and the North-Western and Central Highlands', *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 203 et seq.

[4] 'On the Structure of the North-Western Highlands, and the Relations of the Gneiss, Red Sandstone, and Quartzite of Sutherland and Ross-shire', *Quart. Jour. Geol. Soc.*, vol. xvii (1861), p. 85.

[5] Loc. cit., pp. 92, 93.

Loyal, which has at once hardened the beds and preserved them from removal by denudation. In this place, therefore, there is clear evidence that so far from underlying all the gneiss of central Sutherland, the red sandstone and quartzite of the west are again found resting upon it ten miles to the east of the supposed overlap.'

The detailed mapping by the Geological Survey has proved that these Tongue conglomerates are of Old Red Sandstone age, as they rest unconformably on the folded and eroded edges of the Moine Series and contain pebbles of basal quartzite, pipe-rock, and limestone derived from the Cambrian rocks of the North-West Highlands. The supposed quartzite belonging to the quartzite-limestone series south of Cnoc Craggie is a highly siliceous member of the Moine Series.

The problem of the age of the Eastern Schists was attacked in the field by Callaway.[1] He regarded these rocks as a distinct formation which he termed the Caledonian, divisible into two groups: (1) a Lower or Arnaboll Series, consisting of grey, granitoid, very felspathic gneiss, overlain by dark, striped, hornblendic and micaceous gneisses, passing up through beds of an intermediate character into (2) the ordinary flaggy gneiss, named by him the Hope Series. The latter series is described as normally a thin-bedded, highly quartzose gneiss, merging into a felspathic variety on the one hand and into quartz-schists on the other (Gneissose Flagstones of Murchison). Its uniform lithological characters were traced by him southwards to Loch Broom, and eastwards to Lairg in Sutherland and to Ben Wyvis in Ross-shire. He tried to prove that this Caledonian formation forms a distinct series, newer than, and resting unconformably upon, the Hebridean (Lewisian) Gneiss.

The detailed examination of the Arnaboll region by Lapworth proved that the gneiss on Ben Arnaboll (the Lower Caledonian Series of Callaway) is really a portion of the old floor of Lewisian Gneiss. The mapping of the whole of that area by Peach and Horne showed that the apparently conformable passage from the Arnaboll Gneiss into the Hope Series is deceptive, the two being separated by the Moine Thrust.

The results of Lapworth's work, in so far as they affect the age, composition, and mode of formation of the Eastern Schists, were communicated to the Geologists' Association in 1884 and published in the following year.[2] They are summarized in the Survey Memoir

[1] 'The Age of the Newer Gneissic Rocks of the Northern Highlands', with Notes on the Lithology by Professor T. G. Bonney, M.A., F.R.S., *Quart. Jour. Geol. Soc.*, vol. xxxix (1883), p. 355.

[2] *Proc. Geol. Assoc.*, vol. viii, p. 438.

on the North-West Highlands (pp. 27–9), from which the following quotation is made:

'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 the so-called Laurentian, brought up to the east of the Assynt (Durness-Eireboll) series by gigantic overfolds. The younger is composed of 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 planes 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-building. 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 hälleflintas 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.'

In the course of the survey of the Loch Eireboll region in 1883–4 by Peach and Horne a typical development of granulitic quartz-schists, with bands of garnetiferous mica-schist was mapped in the wide tract, named the Moine, east of Loch Eireboll (Geol. Surv. One-inch Map of Scotland, Sheet 114). Hence the term Moine Schists was applied to these rocks. As the field work advanced, rocks of these types were found to have a wide distribution in the North and Central Highlands. They were recognized by L. W. Hinxman[1] in the Spey valley and in the Monadhliath mountains, to the north of that river, and by G. Barrow[2] in the upper portion of the Dee valley on the south side of the Grampian range. In view of these facts the term Moine Schists or Moine Series has been generally adopted by the Geological Survey for these rocks. E. B. Bailey[3] has applied the term Eilde Flags to rocks of Moine type in the Lochaber district south-east of Fortwilliam.

[1] 'Summary of Progress for 1897', *Mem. Geol. Surv.* (1898), pp. 55, 56; for 1898 (1899), p. 35. [2] Ibid. for 1899 (1900), pp. 26, 27.

[3] 'The Geology of Ben Nevis and Glen Coe', *Mem. Geol. Surv.* (1916), p. 80.

In the area between Loch Eireboll and the Kyle of Tongue, the Moine Schists, whose structures were supposed by Peach and Horne to have been developed by the post-Cambrian movements, were found by them to be associated with a belt of reconstructed Lewisian Gneiss, bounded on both sides by lines of movement (see Sheet 114). No definite evidence relating to the age and origin of the Moine Schists was then obtained by them. As the Eastern Schists were traced southwards through Ross-shire, evidence suggesting their probable sedimentary origin was found. The occurrence in them of colour-banding, false-bedding, and lines of heavy minerals pointed to their clastic character. It seemed as if the siliceous schists might have been originally sandstones; the muscovite-biotite schist and gneiss, an argillaceous rock; and the intermediate types, admixtures of these two kinds of sediment.[1] This view was strengthened by the detection of conglomerate rocks at the base of the Moine Series in contact with Lewisian Gneiss, by B. N. Peach[2] in the area between Loch Carron and Loch Alsh, Ross-shire; by C. T. Clough,[3] in the district of Glenelg (Pl. XIII, 1); and by E. M. Anderson[4] in Glen Strath Farrar, Central Ross-shire.

Fortunately, definite evidence of their sedimentary origin was found in the aureole of contact-altered rocks connected with the plutonic complex of Inchbae and Càrn Chuinneag,[5] Ross-shire. In this belt, hornfelsed shales, slightly altered sandstones, and arkoses pass outwards into mica-schists, quartz-schists, and quartzo-felspathic granulites of the Moine Series in the surrounding country.

The effects of dynamic metamorphism produced by the post-Cambrian movements in the Torridonian strata in Ross-shire, *west of the Moine thrust-plane*, where they approach in structure crystalline schists of Moine type, led Peach to the conclusion that the members of the Moine Series are metamorphosed representatives of the Torridon Sandstone. He inferred[6] that 'the difference between the rocks of sedimentary origin on either side of the Moine thrust-plane in the Loch Carron region is shown to be one of degree of alteration, and not of kind' (see p. 199). On the other hand, Horne favours the hypothesis that the Moine Schists are altered sediments mainly of pre-Torridonian age, modified by post-Cambrian movements, and that they originally formed part of the land barrier

[1] 'Summary of Progress for 1898', *Mem. Geol. Surv.* (1899), p. 8.
[2] 'The Geology of Glenelg, Loch Alsh, and South-East Part of Skye', *Mem. Geol. Surv.* (1910), p. 56.
[3] Ibid., p. 50.
[4] 'The Geology of Central Ross-shire', *Mem. Geol. Surv.* (1913), p. 67.
[5] 'The Geology of Ben Wyvis, Càrn Chuinneag, Inchbae and the surrounding Country', *Mem. Geol. Surv.* (1912), p. 102.
[6] 'The Geology of Central Ross-shire', *Mem. Geol. Surv.* (1913), p. 30.

separating the Cambrian sea in the North-West Highlands from the Upper Cambrian or Lower Ordovician sea to the south, in which the Highland Border Rocks were laid down.

Another interpretation has been advanced by Barrow,[1] who, in his paper descriptive of the Moine Gneisses in Perthshire and Aberdeenshire, shows (1) that in their composition and microscopic structures they are identical with the Moine Gneisses of the North-West Highlands, and (2) that they pass into a zone of rocks known as the Honestones, which lie on the white margin of the Central Highland quartzite (Dalradian). He suggests that the parallel-banded Moine Gneisses are the flaggy margin of this quartzite (p. 190).

Rocks

In the belt of country east of the Moine thrust-plane stretching from the north coast of Sutherland across Ross-shire to Loch Hourn south of Glenelg, the rocks have been arranged by the Geological Survey in two groups:

(*a*) A complex of acid, basic, and ultrabasic gneisses of igneous origin (orthogneisses) resembling Lewisian types of the undisturbed areas west of the Torridon Sandstone. In some localities these are associated with rocks of sedimentary origin (paragneisses) recalling the Loch Maree sedimentary types in the Lewisian Gneiss of West Ross-shire.

(*b*) The Moine Series, including various types of crystalline schist of sedimentary origin which are regarded as younger than group (*a*) and believed to be originally separated from the latter by an unconformity, now to some extent effaced by lines of movement.

The members of both groups have been thrown into great isoclinal folds. The gneisses of Lewisian type have been more or less granulitized, but, in places, the original igneous structures are still preserved. They form inliers in the Moine Series, now exposed by the denudation of members of that series which formerly covered them.

The rocks of igneous origin in these inliers include hornblende-gneiss, pyroxene-hornblende-gneiss, garnetiferous amphibolites, and biotite-gneiss, together with hornblende-schists, and peridotites now represented by talcose chlorite-tremolite-schists. The rocks of sedimentary origin in the Lewisian inliers comprise limestones, calc-silicate-rocks, graphitic mica-schists, and muscovite-biotite-schists. Reference will presently be made to some of the Lewisian inliers in which the various rock-types are best developed.

Before the development of the present structures in the members

[1] 'On the Moine Gneisses of the East Central Highlands and their Position in the Highland Sequence', *Quart. Jour. Geol. Soc.*, vol. lx (1904), p. 400.

of the Moine Series, acid and basic igneous rocks were injected into the sediments, producing in one instance distinct contact metamorphism. The striking example of this contact alteration is the aureole surrounding the foliated granite mass of Càrn Chuinneag, Ross-shire (p. 193). The basic intrusions appear as dykes and sills in the form of epidiorite, hornblende-schist, or chlorite-schist.

After the folding and regional metamorphism of the members of the Moine Series they were invaded by granite masses and their apophyses, which occupy considerable areas on both sides of the Great Glen.

The general description of the Eastern Schists as developed along a narrow belt of country east of the Moine thrust-plane was given in 1907 in the Geological Survey Memoir on the North-West Highlands. The account of the petrographical characters of these rocks was supplied by Teall. The detailed mapping showed that along this belt the types of crystalline schist are remarkably uniform and persistent. The observer may walk for 100 miles along this belt from the north coast of Sutherland to Loch Hourn beyond Glenelg without finding much variation in the lithological characters of the Moine Schists. In Skye, however, near Tarskavaig in Sleat, Clough found an area of schistose rocks resembling the Moine Schists, but in a less altered condition, which had been brought forward by displacements below the horizon of the Moine Thrust. This group was named by him the Tarskavaig-Moine Schists (p. 171).

In the general description referred to above, the rocks overlying the Moine thrust-plane, excluding those of the Lewisian inliers, are grouped in three divisions: (1) mylonized rocks; (2) phyllitic schists, siliceous schists, and limestones, especially characteristic of the Durness-Eireboll region; (3) granulitic quartzo-felspathic schists, frequently referred to as Moine Schists, with which are associated bands of garnetiferous mica-schist.

(1) The mylonized rocks are a characteristic feature of the materials associated with the Moine thrust-plane. The belt varies in width from a few hundred yards to a mile, but, in places, it is absent and the crystalline schists rest directly upon that plane. The mylonites derived from the Lewisian Gneiss vary in colour according to the nature of the materials deformed by the movements. The hornblende-gneisses give rise to the green variety; the pink pegmatites to the pink type; and the acid gneisses with quartzo-felspathic veins to the striped mylonites. Rocks of sedimentary origin likewise show the effects of crushing. Thus the basal Cambrian quartzites are rolled out into thin, siliceous bands in which the clastic constituents are barely observable in the field. The annelid tubes in the pipe-rock are

flattened like ribbons and the sub-zones are not recognizable. Sometimes the thin, platy mylonites have been so intensely deformed by earth stresses that it is often difficult to determine the nature of the original material. The divisional planes of all the mylonized rocks are parallel to the plane of the Moine Thrust and dip to the ESE. at gentle angles.

Teall[1] states that all stages in the deformation of the Lewisian rocks can be traced.

'The original grains of quartz and felspar have been broken, and detached fragments now lie in a crypto- or micro-crystalline matrix which represents the ultimate results of the mechanical action. The plagioclase felspars illustrate the cataclastic effects in the greatest perfection on account of their twin lamellation. The first effect is seen in a simple faulting of the twin-lamellae, and from this action to the breaking up of a large individual into innumerable fragments and the separation of the fragments in the matrix of fine-grained mylonitic material every stage may be followed. The same phenomena may be seen in quartz, especially in quartzites, but when quartz and felspar in juxtaposition have been simultaneously affected they behave somewhat differently. Quartz appears to yield without fracture to stresses tending to produce fluxion more readily than felspar, and what may be termed quartz-flow round angular grains or crystals of felspar may sometimes be observed.'

(2) The phyllitic schists, siliceous schists, and limestones form a distinct sedimentary group in the Eireboll region. The chief constituents of the phyllitic schists are white mica, chlorite, and a microcrystalline aggregate of quartz and felspar. The latter type is usually dark green in colour and has wavy foliation planes. Teall notes that this feature was produced by movements later than the development of the plates of white mica, which, under the microscope, are seen to be bent and broken. The siliceous schists are compact hälleflinta-like rocks, mainly composed of quartz with some flakes of white mica. The limestones are crystalline and consist of calcite with occasional white mica and grains of quartz and felspar.

Near the outcrop of the Moine Thrust the divisional planes of the platy mylonites and the siliceous schists are traversed by fine parallel lines (friction lines), trending generally WNW. and ESE., which is the general direction of movement of the thrust masses.

(3) The granulitic quartz-schists are typical representatives of the Moine Series. They are usually flaggy with muscovite and less frequently biotite. They contain augen of quartz and felspar which may be remnants of original clastic grains.

Evidence of the breaking down of the structures of the siliceous

[1] 'Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), p. 597.

schists close to the Moine thrust-plane by the post-Cambrian movements has been found at various localities between Stromeferry and Loch Alsh and also in Sleat, Skye. It is evident, therefore, that some of these rocks existed as crystalline schists before they reached their present position.

Teall[1] makes the following important observations regarding group (3):

'Under the microscope the main mass of a typical Moine-schist, taken at some distance from the thrust-zone, is seen to be a micro-granulitic aggregate of quartz and alkali-felspar, in which flakes of mica are embedded. The grains of quartz and felspar are of approximately uniform size and shape, and the mica flakes do not merely lie between the constituents of the aggregate but are included in it, so that a single flake may pierce one or more contiguous grains. A rock of this character shows no traces of clastic or cataclastic structures; it is a holocrystalline schist.

'But although these features are common in rocks which cover a very large area to the east of the Moine-thrust, they are not especially characteristic of the rocks immediately overlying the thrust. In these rocks cataclastic structures are not uncommon, and the question has arisen as to whether they represent crystalline schists more or less broken down or sedimentary rocks which are on the way, so to speak, to become Moine-schist. Both views have been held by different members of the Survey, and both views may be right, though not, of course, as applied to one and the same rock. The age and origin of the rocks that have been mapped as Moine-schists is a complicated problem which has not been finally and definitely solved, but abundant evidence has been accumulated to show that under the influence of the post-Cambrian movements rocks of diverse age and origin have acquired a common type of structure, and that true crystalline schists have been simulated if not actually produced.'

Throughout much of the area occupied by the Eastern Schists in the counties of Sutherland and Ross the members of the Moine Series have a double system of folding produced by the post-Cambrian movements. The strike of one system is NNE. and SSW., thus coinciding in direction with the trend of the Moine Thrust, while the other system strikes WNW. and ESE. The combination of these two systems of folding gives rise to rod or 'mullion' structure, the rods trending WNW. and ESE. Where this structure is developed the divisional planes may dip NNE. and SSW., the pitch of the folds being towards the ESE.

In 1923 Sir J. S. Flett[2] described the characteristic features of the members of the Moine Series, based on an intimate knowledge of

[1] Op. cit., p. 599.

[2] 'The Geology of the Lower Findhorn and Lower Strath Nairn', *Mem. Geol. Surv.* (1923), pp. 54–5.

the petrographical characters of the rocks which had been mapped by the Geological Survey between the Moine thrust-plane and the Grampian range. On account of its importance his description is given below:

'Three types of rock predominate, viz.:

'(*a*) A white quartzite, quartz-schist, or quartz-granulite which has the composition of a sandstone or felspathic sandstone.

'(*b*) A group of dark mica-schists often with large plates of white muscovite and segregation bands or knots of quartz and felspar elongated parallel to the foliation. These rocks are often garnetiferous, but they seldom contain kyanite or staurolite.

'Their composition indicates that they were originally clay rocks or shales, and occasionally they show traces of graphite which may have arisen from coaly matter or plant debris, though true graphite-schists practically do not occur in the Moine Series. The rocks of this group are sometimes termed the Pelitic Schist or the Muscovite-biotite-gneiss.

'(*c*) The third type, which is the commonest of all, is the semi-pelitic, and is a mixture in fairly equal proportions of the two preceding. It consists essentially of quartz, alkali-felspar (with oligoclase), and biotite. Muscovite, garnet, epidote, iron ores, zircon, and apatite are also frequently present in small amount. As a rule, these rocks are rather finely crystalline, the individual grains being one or two millimetres in diameter. The mica flakes are parallel, and generally are fairly evenly disseminated through the quartz and felspar, but often the mica forms sheets or folia which give the rock a slabby or flaggy parting that may be very conspicuous in large exposures of the semi-pelitic granulites. It is never sufficiently perfect to enable these rocks to be used as paving stones, but in sea cliffs and quarry faces it is usually perfectly obvious. These rocks have been originally argillaceous sandstones, probably red in colour from the abundance of iron oxides now absorbed by the development of biotite. It seems as if they were mostly of medium to fine grain; true conglomerates at any rate were not numerous, and it is in every way probable that they and the alternations of shale built up a great thickness of sedimentary rock.

'(*d*) True limestones do not occur among the Moine rocks of Sheet 84, though they are found at Rebeg, six miles west of Inverness (Sheet 83), and to the east of Cullen, in Sheet 96, on the eastern margin of the Moine Series. Some of the Moine sediments are undoubtedly calcareous; they may even contain original calcite. Their most characteristic mineral, however, is epidote or zoisite, usually accompanied by garnet and sometimes by green hornblende. These have been calcareous and argillaceous sandstones and thin bands of this class of rock occur in every typical area of Moine gneisses. These zoisite-hornblende-granulites, in fact, serve as one of the distinguishing marks of this group as they are restricted in occurrence to the Moine rocks and have many petrographical characteristics which make their identification a matter of no great difficulty.

'Of the Moine Series as a whole it is fairly clear that they are a great "continental" formation. The scarcity of limestones in so thick an assemblage of rocks renders their marine origin very improbable. In all likelihood the sandstones were of red colour; they may even have been desert deposits. The absence of graphitic schists and other evidence of carbonaceous deposits is, on the whole, in favour of their continental origin. In many respects they resemble the Torridonian, but they have also affinities to the Old Red Sandstone and the Trias. Presumably they covered a very large area, and it is by no means improbable that they are identical in origin and age with the Seve gneisses and schists of Norway and Sweden. On the other hand, there are in the true Lewisian rocks of Lewis, certain bands which have many of the characteristics of the Moine Series of the North-eastern Highlands [p. 52].

'Towards the south-western margin of its extent the Moine Series changes in general character. Quartzose facies become more prevalent, and a broad belt of nearly pure quartzite frequently appears as we approach the country occupied by the black schists, phyllites, and limestones of the Blair Athol or Central Highland Series [Dalradian].'

Flett states that the special characteristic of the members of the Moine Series is their similarity in composition and in metamorphism over the whole of the great area which they occupy in the Highlands of Scotland. The metamorphism is of the regional type induced by movement and pressure; but, in the vicinity of granite masses, traces of contact alteration can occasionally be detected.

The accessory minerals in the Moine Series include magnetite, ilmenite, zircon, sphene, epidote, apatite, and rutile, which are sometimes arranged along the lines of bedding in the strata. Layers of pebbles appear in certain beds in the succession.

Some chemical analyses have been made of examples of Moine Schists which furnish additional evidence of their sedimentary origin. Teall analysed a specimen of siliceous granulite collected near Bernera north of Glenelg (Geol. Surv. Sheet 71[1]), to compare with the analysis of a specimen of Torridonian grit from the ground not far to the west. The results showed that the Moine rock contained 8·64 per cent. more silica than the Torridonian grit, and that the proportion of potash to soda is considerably greater.[2]

A typical quartzo-felspathic Moine granulite from near Glencassley Castle, about eight miles west of Lairg, Sutherland (Geol. Surv. Sheet 102), has also been analysed. Dr. H. H. Read[3] gives a table showing the chemical composition of the rocks from Glen

[1] This and similar references on the following pages are to the Sheets of the Geological Survey Map of Scotland on the scale of one inch to a mile.

[2] 'The Geology of Glenelg, Loch Alsh and South-East Part of Skye', *Mem. Geol. Surv.* (1910), p. 54.

[3] 'The Geology of Strath Oykell and Lower Loch Shin', *Mem. Geol. Surv.* (1926), p. 134.

Cassley and from Glenelg, as compared with that of the Cullen quartzite, Banffshire, and with the composite analysis of 371 sandstones used for building purposes taken from a publication of the United States Geological Survey. He infers that the granulite from Glen Cassley is chemically quite like the Moine granulite from the Glenelg district and the Cullen quartzite of Banffshire. 'It is a felspathic sandstone, composed mainly of quartz, with acid plagioclase and mica, and can be compared with the average of 371 sandstones from which it differs in having more alumina and alkalies, due no doubt to the greater amount of felspar in the granulite.'

Dr. Read[1] has also compared the analysis of pelitic schist from Corriemulzie, Ross-shire (Geol. Surv. Sheet 102) with the composite analysis of fifty-one Palaeozoic shales and finds that the two rocks are chemically alike. He infers that the pelitic schist is a regionally metamorphosed shale of normal composition.

Certain types of the Moine Series, supposed to be of sedimentary origin but differing widely in petrographical characters from those above indicated, have been described by Dr. H. H. Read[2] and Dr. J. Phemister.[3] These include several varieties which are named the hornblendic rocks of Durcha type, a locality about two miles east of Invercassley, in the valley of the Oykell, Sutherlandshire. The types range from hornblendic rocks to quartzo-felspathic granulites with scattered hornblende crystals (p. 185).

With the exception of the hornblendic rocks of Durcha type it is apparent that there is a vast amount of evidence pointing to the sedimentary origin of the members of the Moine Series. No fossils have yet been found in the members of this series.

DISTRIBUTION AND GEOLOGICAL STRUCTURE

The members of the Moine Series, including rocks of Moine type south-east of Glen More (the Great Glen), occupy an extensive area in the Highlands, amounting approximately to about 4,000 square miles. Their north-west limit, as previously indicated, is defined by the Moine Thrust, the most easterly of the great post-Cambrian displacements. Along their south-east margin they are bounded by the Dalradian Series, stretching from the counties of Banff and Aberdeen to Argyllshire.

The plane of the Moine Thrust, dipping to the ESE. at gentle angles, is clearly displayed in several natural sections, such as the

[1] Ibid., p. 136.

[2] Ibid., p. 144. See also 'Geology of the Country around Golspie, Sutherlandshire', *Mem. Geol. Surv.* (1925), p. 19.

[3] 'Summary of Progress for 1922', *Mem. Geol. Surv.* (1923), p. 108.

steep sea cliff east of the mouth of Loch Eireboll, the Stack of Glencoul, near Knockan in Assynt, and between Stromeferry and Loch Alsh. In some sections where the rocks are continuously exposed with a similar dip and strike, there is an apparent passage from recognizable Cambrian quartzites through mylonized siliceous rocks into Moine Schists, without any visible disruption line. In such examples the boundary has been drawn at the outcrop of the mylonized rocks: where they are absent, the base of the granulitic schists marks the western limit of the Moine Series. In those areas where the grits of the Torridon Sandstone are intensely sheared, with partial granulitization of the quartz and felspar and the development of sericitic mica, it is difficult to locate the exact position of the Moine Thrust, and a provisional boundary line has there been drawn.

Before describing the development of the Moine Series in the Highlands, attention will first be directed to the gneisses of Lewisian type appearing as inliers in this Series.

INLIERS OF LEWISIAN GNEISS IN THE MOINE SERIES

The gneisses of Lewisian type which have been mapped by the Geological Survey as inliers occur in the counties of Sutherland, Ross, and Inverness.

North Sutherland District

Several inliers of gneiss of Lewisian type appear in the north of Sutherland (Geol. Surv. Sheet 114). The westerly one, which has been traced for eight miles along the west slope of the Moine moor (A' Mhòine) to Meall a' Bhaid Tharsuinn west of Loch Hope, consists mainly of granulitic biotite-gneiss, the original structures having been largely effaced by the post-Cambrian movements. The central belt, trending in a south-west direction from the village of Tongue by Ribigill and Lochan Hacoin, contains types which Teall regarded as allied to Lewisian rocks occurring in the pre-Torridonian shear-zones. The easterly belt, about two miles broad, has been followed inland from the coast for seven miles along the west side of the Borgie River to near Loch Creagach. Teall[1] has compared the granular gneisses of this tract to the corresponding types in the undisturbed Lewisian Gneiss of the western area.

No trace of a conglomeratic rock has been observed along the boundaries between these Lewisian gneisses and the Moine schists in North Sutherland.

[1] *Geological Structure of the North-West Highlands* (1907), p. 600.

Glenelg District

The most important development of Lewisian rocks not far to the east of the Moine thrust-plane occurs between Loch Alsh and Loch Hourn to the north and south of Glenelg (Geol. Surv. Sheet 71). It presents certain features which immediately arrest attention. The area was mapped by C. T. Clough,[1] the results of whose work are here briefly presented.

The Lewisian rocks form well-marked belts, never more than two miles broad, striking generally NNE., the dip of the foliation planes being to the ESE. These belts are separated from each other by bands of Moine Schist. The most striking feature of the Lewisian rocks is the occurrence in them of persistent beds of limestone associated with gneisses of sedimentary origin (paragneisses) traceable across the area. They occur with gneisses of igneous origin (orthogneisses), and others which, in the present state of knowledge, cannot be referred to either class. Having failed to obtain evidence that the paragneisses are unconformable to, and younger than, the orthogneisses, Clough adopted the hypothesis that the oldest rocks are of sedimentary origin which were injected and altered by igneous rocks, intruded under considerable pressure. Owing to the intense folding and metamorphism of these rocks, due mainly, if not wholly, to post-Cambrian movements, the difficulty of distinguishing the various paragneisses in this area has been largely increased.

Paragneisses. The bands of limestone extending from Totaig on Loch Alsh to Loch Hourn, a distance of about ten miles, are white on fresh fracture and remarkably uniform in character. The carbonate grains consist chiefly of calcite, but dolomite also occurs. Forsterite is an abundant constituent: indeed, the banded appearance of the rocks is due to subparallel layers, from half an inch to four inches broad, which contain less forsterite than the intervening layers.

In addition to forsterite, the other silicates present include diopside, phlogopite, tremolite, serpentine, spinel, and black hornblende. The diopside is a characteristic feature forming masses from a few inches to several yards in breadth, edged by serpentinous material (Pl. XIII, 2). The phlogopite sometimes occurs in large plates enclosing grains of calcite. Garnet is occasionally met with in impure bands in association with black mica and hornblende. Scales of graphite have been observed in quartzose lumps and in nodules of diopside.

A schistose type of rock occurring with the limestone contains small flakes of brown mica and specks of pyrites. The resemblance

[1] 'The Geology of Glenelg, Loch Alsh and South-East Part of Skye', *Mem. Geol. Surv.* (1910), p. 19.

PLATE XIII

1. Supposed conglomerate-schist of Moine Series, 2½ m. SSW. of Glenelg.

2. Supposed Lewisian marble with diopside nodules, 1½ m. NE. of Glenelg.

of this type to certain altered sediments in the Dalradian Series in the Braemar district was noted by Barrow. Another type near the limestone, composed of layers of zoisite and microcline, with dark layers of pyroxene, calcite, and sphene, was regarded by Teall as allied to rocks found with limestones in Donegal and the South-Eastern Highlands.

Impure bands of various types occur. One variety contains a proportion of quartz and felspar, in addition to tremolite, sphene, pyrite, pyrrhotite, and graphite. The last of these minerals sometimes forms well-marked streaks and the rock becomes a graphite-schist. Another variety shows grains of calcite lying between scales of biotite and chlorite.

Brown biotite-schist, garnetiferous biotite-kyanite-gneiss, and garnetiferous granulitic biotite-gneiss, associated with the limestones, may represent original shaly members of the sedimentary series. At some localities there is a prominent development of garnetiferous biotite-gneiss with kyanite, which, at first sight, might be regarded as belonging to the pelitic gneiss of the Moine Series. Clough,[1] however, inferred that 'the scarcity or absence of white mica, the brown colour of the biotite, the abundance of kyanite, the character of the hornblendic laminae, and the presence of the thoroughly streaked out and granulitized pegmatite veins, all tend to show that such an impression would be incorrect'.

Certain granulitic biotite-gneisses without kyanite but richly garnetiferous, are traversed by lenticular streaks, consisting mainly of red felspar, quartz and minute biotite. They resemble the small pegmatites in the Moine Series but differ from the latter in being almost invariably in a granulitic condition and being crossed by a foliation parallel to the axial planes of the folds affecting the country rock. With the other constituents they form a veined gneiss resembling the 'adergneiss' of Sederholm.

Eclogite, Garnet-Amphibolite, and certain Hornblende-Schists. These rocks are well represented in the Lewisian Gneiss of this inlier. In their field relations the eclogites and some of the hornblende-schists resemble the early basic rocks in the undisturbed Archaean Series west of the post-Cambrian displacements in Sutherland. The typical eclogite is a massive rock with pale green and deep red tints, the former being due to omphacite and the latter to garnet, but it often passes into garnet-amphibolite, the omphacite being replaced by dark hornblende. The gradual passage of eclogite and garnet-amphibolite into hornblende-schist at some localities suggests that the latter may have resulted from the alteration of the former, but definite evidence proving this conclusion has rarely been observed.

[1] Ibid., p. 28.

Thinly-banded hornblendic gneiss, and gneisses with few ferro-magnesian constituents, are also features of this inlier.

Serpentine, Pyroxenite, and other Ultrabasic Rocks. In the more acid gneisses, ultrabasic rocks composed of hornblendite and biotite-hornblendite are of common occurrence in the form of knots and lenticles. Large bands of impure serpentine with some pyroxene have also been observed, sometimes in such a massive form that they might be mistaken for intrusions later than the development of the folds of the district. A few examples, however, of foliated basic and ultra-basic rocks showing intrusive junctions with the gneisses of the complex have been recorded. They are traceable for short distances and may represent the basic and ultrabasic dykes in the Archaean Series in the west of Sutherland.

The development of pseudo-conglomeratic structure by mechanical movements, in the gneiss of this inlier north of the area mapped by Clough, is worthy of note. On the north shore of Loch Alsh near the headland of Avernish, the rocks consist of fine- and medium-grained, granulitic, micaceous gneiss and hornblende-biotite-gneiss with bands of hornblende-biotite-schist and green chlorite-schist, the strike being nearly north and south and the dip easterly. The rocks are repeated by sharp inverted folds, whereby lenticular pieces of the granulitic gneiss have been wrenched off and enclosed in the bands of chlorite-schist. Subangular and rounded edges have been developed in these blocks by interstitial movements, and the matrix of chlorite-schist winds round the pseudo-pebbles (Pl. XIV).

Relations of the Lewisian Rocks to the Moine Series. On the south-east shore of the Sound of Sleat between Port a' Gharàidh, about a mile and a half south-west of Glenelg, and the Sandaig Islands, a band of conglomerate-schist[1] lies at the base of the Moine Series and rests immediately upon the Lewisian Gneiss. It occurs there in inverted order dipping to the ESE. below the Lewisian Gneiss (Pl. XIII, 1). Its thickness is variable but it rarely exceeds from twenty to thirty feet. The matrix contains flakes of black or brown biotite, much crumpled, together with abundant epidote. Hornblende and small garnets are also found in some localities. The hornblende appears partly in long needles which are probably of secondary origin and of the same age as the spears of actinolite that occur abundantly in the pelitic Moine schists in the neighbourhood. Hornblendic lenticles, some several feet in length, which appear to have been derived from the adjacent hornblende-schists in the Lewisian Gneiss have been observed. The smaller pebbles are composed mainly of quartz and red felspar, the larger ones of a foliated rock resembling the pink

[1] 'The Geology of Glenelg, &c.' (1910), p. 47.

PLATE XIV

CRUSH-CONGLOMERATE IN LEWISIAN GNEISS AFFECTED BY THRUSTING, SHORE, W. SIDE OF AVERNISH, KIRKTON OF LOCH ALSH

felspathic bands in the Lewisian Gneiss. Regarding this outcrop Clough[1] states that 'the exposures are sufficiently continuous to make it clear that the conglomerate-schist is not separated by a distinct thrust, either from the Lewisian Gneiss above or from the other Moine schists below'.

North of Loch Alsh, Peach mapped several narrow infolds of Moine Schist, occurring in the northern continuation of the Glenelg inlier about two and a half miles north-east of Kirkton of Lochalsh. The altered sediments show increasing metamorphism eastwards on each successive fold, and the intervening bands of gneiss are almost wholly granulitized. Two exposures of the conglomeratic rock are found in connexion with these infolds. One rests upon granulitic hornblende-biotite-gneiss and passes below Moine schists to the east. The other is an isolated exposure. The matrix of the rock in both localities is holocrystalline, and is composed of quartz, felspar, hornblende, biotite, muscovite, and epidote. It encloses fragments of granulitic gneiss and quartz.[2]

Central Ross-shire District

In this district several inliers of Lewisian Gneiss have been mapped and described by the Geological Survey.[3] They were first observed (in 1895) by Peach[4] to the south of Strath Bran, and during subsequent years they were mapped by L. W. Hinxman, R. G. Carruthers, C. B. Crampton, and E. M. Anderson. Some of these masses furnish important evidence relating to the component members of the complex and the contact metamorphism of the paragneisses before the deposition of the Moine sediments. Some of these masses of special interest are here referred to (Geol. Surv. Sheets 82, 83, and 92).

(i) *Scardroy Inlier*. This mass occupies the largest area in Central Ross-shire, stretching from a point four miles above Scardroy in the valley of the River Meig to the northern slopes of Sgùrr a' Ghlas Leathaid, a distance of about eight miles (Geol. Surv. Sheet 82).

From the description by L. W. Hinxman it appears that the dominant type of rock of igneous origin is a granulitic, pink, felspathic gneiss with thin folia of biotite-gneiss, biotite-hornblende-gneiss, and hornblende-gneiss. Basic and ultrabasic materials also occur which may represent early intrusions into the original complex. One example seems to have been a hornblende-peridotite, now sheared into a talcose chlorite-tremolite-schist. Another variety with

[1] Ibid., p. 51. [2] Ibid., p. 56.

[3] 'The Geology of Central Ross-shire', *Mem. Geol. Surv.* (1913), p. 33; 'The Geology of the Country round Beauly and Inverness', *Mem. Geol. Surv.* (1914), p. 17.

[4] *Annual Rep. Geol. Surv.* for 1895 (1896), pp. 19–20.

a variable amount of foliation may be termed a garnetiferous hornblende-gneiss; sometimes it is massive with little parallel structure and consists of hornblende and large garnet aggregates; sometimes it is well foliated and felspathic, and passes into hornblende-schist or chlorite-schist.

Paragneisses. Rocks of sedimentary origin occur within this inlier. Granular crystalline limestones containing flakes of dark-green biotite and crystals of green amphibole associated with calc-silicates have been found. Among the last is a rock resembling a calc-silicate-hornfels, and described by Flett as a scapolite-pyroxene-gneiss.

Relations of the Lewisian Rocks to the Moine Series. There is good evidence of discordance between the two formations at various points along the margin. Thus in Coir' a' Bhuic, about three miles west of Scardroy, the Moine granulites rest upon basic hornblende-gneiss in the higher part of the corrie, while near the foot of the crags it is in contact with the acid Lewisian gneisses. Again at the west margin of this inlier additional evidence of the transgression of one member of the Moine Series across several members of the Lewisian complex has been found by Carruthers. In Allt a' Choire Fhionnaraich, a stream flowing south into Loch Monar, the Moine granulites, when followed along the strike, are successively in contact with graphite-schist, calc-silicate bands and garnet-amphibolite. The junction is well defined but no conglomerate nor any indication of thrusting was observed.

The field relations around this inlier show that both formations have been affected by the post-Cambrian movements and have shared in a common system of foliation. In a few localities, however, the original structures of the Lewisian rocks are still preserved.

(ii) *An Cruachan Inlier.* This mass, which lies about three miles SSW. of Loch Monar, and occupies about a square mile of ground (see Fig. 21, p. 180), furnishes evidence of special importance. Rocks of igneous origin include the usual types of hornblende- and biotite-gneisses together with eclogite. A highly graphitic schist containing andalusite and a brown biotite-schist are closely associated with the eclogite. The andalusite-graphite-schist indicates that the paragneisses have undergone contact alteration of the hornfels type, without the contiguous Moine schists being similarly affected. This inlier also shows the discordance between the two formations, for the siliceous Moine schists which almost completely surround the mass are in contact successively with the graphite-schist, the biotite-hornblende-schist, and the brown mica-schist of the Lewisian complex.

(iii) *Glen Strath Farrar Inlier.* This belt is traceable for eight miles from Meall Gharbh west of Sgùrr na Lapaich in a north-east direction to Inchvuilt, on the River Farrar, and thence northwards to Sgùrr na Mùice. The rocks forming this inlier have been mapped by E. M. Anderson, who arranged them in the following three groups: (1) those which from their mineralogical and chemical composition are altered sediments; (2) those which on similar grounds are gneisses of igneous origin; (3) a number of types which cannot yet with certainty be referred to either of these two classes.

Orthogneisses. In addition to the biotite-gneisses the rocks of igneous origin include bands of hornblende-rock, with or without garnets, occurring as knots and lenticles varying from a few inches to many yards in thickness. They are usually foliated and are more coarse-grained than the types of epidiorite occurring in the Moine Series. One of the characteristic features of the Lewisian rocks of this inlier is the abundance of bands and lenticles of hornblende-schist. These rocks are traversed by pegmatites, which can be readily distinguished from those in the surrounding Moine schists. They are highly sheared and have been almost completely granulitized, now forming a fine-grained aggregate of quartz and felspar with small flakes of mica. The Moine pegmatites, on the other hand, have been but slightly affected by movement and show large crystals of quartz, felspar, and mica. This distinction is accounted for on the supposition that the pegmatites in the Lewisian Gneiss of this inlier are older than the Moine Series and were deformed by post-Cambrian movements, while the Moine pegmatites were contemporaneous with, or later than, the Moine movements.

The rocks of doubtful origin include widely distributed, thin calc-silicate bands and various types of micaceous granulite.

Relations of the Lewisian Rocks to the Moine Series. The rocks of this inlier are almost entirely surrounded by siliceous granulites of the Moine Series. At several localities along the margin examples of conglomeratic structure have been observed. Thus the conglomerate can be traced for a mile or more to the south of the River Farrar and on the eastern slope of Sgùrr na Mùice two miles north of that river. The coarsest type consists of elliptical blocks, composed partly of siliceous granulite and partly of quartzite enclosed in a micaceous matrix. In one place the matrix is highly epidotic recalling the epidotic grits at the base of the Torridon Sandstone in Ross-shire where they have been sheared by the post-Cambrian movements. Regarding the character of this conglomerate Anderson[1] makes the following statement:

'If these fragments have been derived from an underlying Lewisian floor, the absence of included fragments of hornblende-schist, and of the other

[1] 'The Geology of Central Ross-shire', *Mem. Geol. Surv.* (1913), p. 67.

unrepresented members of the complex, may be accounted for on the supposition that these rocks proved less resistant than the siliceous types, and that pebbles of these substances originally present in the conglomerate, have become unrecognizable under the shearing movements. They may perhaps be represented by certain irregular micaceous patches in the groundmass.'

(iv) *The Fannich Inlier*. In the Fannich Mountains, six miles north of Auchnasheen Station, rocks of Lewisian type appear in a great recumbent fold, underlain and overlain by pelitic members of the Moine Series (Geol. Surv. Sheet 92). The prominent type is an acid biotite-gneiss with knots, lenticles and broad bands of hornblende-rock, epidosite and hornblende-schist. At one locality an example of an epidote-pyroxene-granulite has been observed, containing 'epidote in grains and crystals, pale-green pyroxene, hornblende (scarce), water-clear felspar and quartz, forming an irregular mosaic, with sphene as an accessory'.[1] Certain bands composed of green or greenish-brown hornblende and oligoclase with some sphene appear to have the characters of intrusive dykes. On the northern face of the recumbent fold two bands of acid gneiss containing hornblendic masses appear in Allt na Goibhre. In the higher band the foliation of the acid gneiss is almost at right angles to that of the enclosed basic rock, a structure resembling that occurring frequently in the Archaean rocks of the Gruinard district in west Ross-shire.

No direct evidence of an unconformity between the Lewisian Gneiss and the pelitic members of the Moine Series was observed in the Fannich region.

Loch Ness District

Glen Urquhart Inlier. About four miles west of Loch Ness a small area of gneisses partly of igneous and partly of sedimentary origin, intruded by foliated serpentine, occurs on the slope south of Loch Gorm and stretches south-eastwards into Glen Urquhart (Geol. Surv. Sheet 83). This mass has been regarded by the Geological Survey as probably a core of Lewisian rocks surrounded by Moine schist. The strike of the rocks is north-west and south-east, which, as previously indicated, is the general trend of the Lewisian Gneiss to the west of the post-Cambrian movements, and almost at right angles to that of the adjacent Moine Series. From observations on the pitch of the folding, E. H. Cunningham Craig [2] grouped the members of the com-

[1] 'The Geology of the Fannich Mountains and the Country around Upper Loch Maree and Strath Broom', *Mem. Geol. Surv.* (1913), p. 66.
[2] 'Geology of the Country round Beauly and Inverness', *Mem. Geol. Surv.* (1914), p. 20.

plex in the following order, though inversion may have taken place before the folding:

(3) Felspathic, banded gneisses with basic patches and lenticles.
(2) Rusty, micaceous gneiss with kyanite.
(1) Limestone.

Arranged as an anticline with the limestone at the base, the gneisses form recognizable zones, the highest appearing at the sides of the arch. The limestone, varying in thickness from 30 to 40 feet, is a crystalline white marble with lime-silicates in some of the beds. Thin bands are composed mainly of tremolite, and, near the top, they contain malacolite and tremolite with some biotite and wollastonite. Some of the impure varieties, when examined under the microscope, show the characteristic features of a calc-silicate-hornfels. Small veins of pegmatite composed chiefly of alkali-felspar with quartz, biotite and tremolite traverse the calcareous rocks.

The impure limestone at the top passes upwards into rusty mica-schist followed by coarsely crystalline muscovite-biotite-gneiss with large crystals of kyanite and occasionally graphite. Next in order come banded felspathic gneisses usually with muscovite and biotite, and containing knots and lenticles of basic, hornblendic material, thereby resembling the gneisses of igneous origin in the Lewisian inliers of Central Ross-shire.

The serpentine intruded into these gneisses is foliated, but its age has not been definitely determined. At the margins of the mass it passes into a talc-schist. Under the microscope the least altered variety shows granular olivine in a talcose matrix with iron ores, chlorite, and some tremolite.

Relations of the Lewisian Rocks to the Moine Series. Different members of the Lewisian Gneiss come in contact with the Moine schists but no trace of a conglomerate at the line of junction has been observed. The rocks are intimately folded with each other and in places it is difficult to locate the precise boundary line between the two formations.

Petrographical Characters of the Inliers of Lewisian Rocks among the Moine Gneisses of the North of Scotland

Sir J. S. Flett[1] has described the petrographical characters of the inliers of Lewisian rocks among the Moine gneisses in the north of Scotland. On account of the extreme importance of this report and its bearing on the correlation of these rocks with corresponding types

[1] 'Summary of Progress for 1905', *Mem. Geol. Surv.* (1906), p. 155.

in the undisturbed Lewisian Gneiss areas along the western seaboard of Sutherland and Ross, the greater part of it is given below:

'*Orthogneisses*. By far the commonest kind of rock in these Lewisian inliers is *hornblende gneiss*, consisting essentially of green hornblende, orthoclase and plagioclase felspar, and quartz. The foliation is sometimes very perfect, passing occasionally into a straight parallel banding, but at other times may be almost wanting, and the resemblance to granites, tonalites, and diorites in the hand specimens is then very great. The abundance of the essential ingredients varies greatly, some specimens being pink and highly quartzo-felspathic, while others are dark and rich in hornblende. The amphibole is similar to the common green hornblende of granites and diorites, but is occasionally brownish-green in thin section. Oligoclase and albite (or oligoclase albite) are on the whole more common than orthoclase, but both are probably always present; microcline and varieties of plagioclase more basic than oligoclase, are very rare. The accessory minerals, sphene, apatite, magnetite, and zircon are usual in the slides. Epidote is commonly so abundant that it might almost be regarded as a characteristic and essential mineral, and very frequently it contains brown cores of idiomorphic or hypidiomorphic orthite. The darker or femic hornblende gneisses contain least orthoclase and quartz. They pass gradually into rocks which may be described as *amphibolites* or *epidote-amphibolites*. Many of these contain large pink garnets, dotted with enclosures of quartz and magnetite. Garnet appears also in the hornblende gneisses, but is far less common there.

'The prevalent epidote is pale yellow in thin section and bright yellow in the hand specimen. Its abundance was noted by Dr. Peach as characteristic of the Lewisian gneisses. It is rare in the Moine granulites as a rule, though a colourless or pale grey clinozoisite or zoisite characterises certain bands of the Moines which have been described as zoisite granulites and zoisite hornblende granulites. There is little danger, however, of confounding these rocks, which are evidently metamorphosed calcareous sediments, with the epidote hornblende gneisses of the Lewisian. Still more distinctive is the great frequency with which orthite occurs in the latter rocks. This mineral has only once or twice been seen in the Moine granulites, but is exceptionally abundant in some of the more acid gneisses of the Lewisian inliers. It is always surrounded by a narrower or broader border of epidote in parallel growth. The whole aggregate is usually not idiomorphic, though the orthite centre frequently shows good crystalline outlines.

'The hornblende gneisses occasionally contain crystals of pyroxene, bright green in colour, and in the microscopic slides paler than the accompanying hornblende and far less dichroic. Usually its amount is small, but sometimes it nearly completely replaces the amphibole, without, however, producing any very marked change in the macroscopic appearance or in the structure of the rock. Its prismatic cleavage is usually very good, and occasionally a fine striation appears parallel to the basal plane. The extinction angle is about 40°. Both the amphibole and the pyroxene are in short, irregular grains, which show little trace of crystalline form. Either mineral may enclose patches of the other, usually not in parallel growth. Orthoclase and acid plagioclase, quartz, magnetite, epidote are the other components. Sphene is often abundant, and may have a strong brown colour and distinct dichroism. Biotite and orthite are rare. In one of these rocks from Allt Toll a' Mhuic, the epidote is pale yellow green, like the pyroxene, very feebly dichroic, and is penetrated in all directions by intergrowths of quartz, so that it resembles vermicular micropegmatite. Other specimens came from Meall Cosach, and Allt Riabhachain.

'Nodules or streaks of bright yellow colour, composed of epidote and augite with a little quartz, hornblende, iron ores and sphene sometimes occur in the hornblende gneiss. They are essentially of the same nature as the epidosite segregations frequently observed in hornblendic schists, but the abundance of augite in them is a distinctive feature. They do not seem to form any considerable mass of rock. Their epidote not unfrequently has fairly good crystalline faces, but the augite and quartz are always irregular. Other *epidosites* which may also contain bright green pyroxene, occur in connection with the marbles and calc-silicate rocks and may be altered sediments.

'Though many of the hornblende gneisses are free from biotite, this mineral is a very common ingredient of them, especially of those which are comparatively rich in felspar and in quartz. It is always brown, strongly dichroic (pale yellow brown to dark brown, nearly black), and is often aggregated into clusters of separate folia with the amphibole. The *biotite hornblende gneisses* are more frequent than the *pyroxene hornblende gneisses* and mark transitions to the *biotite gneisses*—free from hornblende—and the *muscovite biotite gneisses*. They are readily detected in the hand specimen by the lustrous mica coating the cleavage planes. Gneisses containing muscovite are scarce. They are relatively quartzose, and often rich in microline and orthoclase; sphene is rare in them, but the epidote and orthite above described are almost constantly present and are often conspicuous in the micro-slides. A little vermicular micropegmatite also is frequent, but garnet has not yet been found in any of the acid orthogneisses. The *pegmatite veins* so characteristic of the Lewisian area west of the Moine thrust-plane occur also in these inliers, being represented by pale gneisses consisting mainly of quartz and orthoclase with a small amount of both black and white micas.

'Allied to the garnetiferous amphibolites above-mentioned as forming the femic end-facies of the hornblende gneisses are certain rocks consisting of large garnets, green hornblende, pale green augite and quartz. These may be classed as *eclogites*. They are not numerous, but both their presence and their association with altered sedimentary gneisses is of considerable significance as linking certain Lewisian inliers with the old gneiss of the Loch Maree area. In these eclogites there are very many garnets, both large and small, pink in section and giving the rock a brownish colour in the hand specimen. Quartz is abundant in certain folia; felspar is absent; the hornblende is pale green and only feebly dichroic; the augite clear green and weathering to grass green amphibole. Much of the augite has basal striation; magnetite, rutile and apatite are present, but the ubiquitous epidote is almost absent. With the exception of the rutile none of the ingredients shows any crystalline form. The amphibole often surrounds the augite in parallel growth and the larger crystals of both minerals are spotted with rounded enclosures of quartz. The best example of the eclogites is one sent in from An Cruachan by Dr. Crampton.

'The structure of these gneisses, amphibolites and eclogites is generally that which has been designated homœoblastic by Becke and granoblastic by Grubenmann.

'The main ingredients are all of very similar size and devoid of crystalline outlines. Rutile, sphene and occasionally apatite and iron ores form well-shaped, though small crystals, but they are the only exception to the general rule. Hornblende is granular rather than elongated; augite occurs only in rounded grains; the garnet, quartz and felspar never show any but the most rudimentary crystalline outlines. When much mica is present there is a tendency to the development of minute foliation, but this occurs so seldom that it is never of importance. Occasionally the larger crystals of certain minerals such as garnet and felspar are studded with small rounded enclosures of quartz (poikiloblastic structure). The orthite is usually partly idiomorphic, but the epidote which surrounds it has less commonly crystalline boundaries. Although these rocks are all of igneous origin, their structures have been completely defaced by the action of metamorphic agencies.

'*The ultrabasic rocks* (peridotites, &c.) which occur in the Lewisian Gneiss west of the Moine thrust-plane, whether as members of the fundamental gneiss or as dykes of later age intersecting it, occur also in these inliers. They are represented mostly by unctuous dark green schists composed of pale coloured talc, chlorite and tremolite or actinolite. Iron ores and apatite are the usual accessories, and a small percentage of carbonates (mostly calcite) is very commonly also present. The principal minerals are chlorite and talc; their relative proportions vary considerably, but talc usually preponderates. The chlorite is of that variety which gives grey polarisation colours and is usually polysynthetic (clinochlore). The tremolite is colourless or very pale green in thin section, contains few enclosures and has imperfectly idiomorphic transverse sections. These rocks are schistose in structure.

'In several of the specimens undestroyed crystals of olivine and other minerals remain, weathering to serpentine and surrounded by a winding (helizitic or nematoblastic) schistose matrix of talc, tremolite and chlorite. These rocks consequently exhibit the relict structure (Becke) or palimpsest structure (Sederholm) which arises from the incomplete transformation they have undergone.

'Near Carnock, Strathconon, Mr. Hinxman has mapped talc-chlorite-tremolite schists, tremolite schists, and talc-tremolite schists with kernels of olivine, in one of the Lewisian inliers. These rocks contain a variable quantity of calcite and iron oxides. The olivine is weathering by ordinary epigenetic processes to a meshwork of green serpentine, which lines the cracks and covers the surface of the original mineral. An interesting ultrabasic rock from Sleugach, River Orrin, consists principally of colourless polysynthetic clinochlore, with acicular tremolite. In this matrix lie masses of olivine weathering to a network of serpentine and magnetite, the interstices of which contain still fresh olivine, and large crystals of nearly colourless pyroxene, the cracks of which are edged with bright yellow chloritic decomposition products. At Carn-na-Creadha there is a tremolite rock with large green pseudomorphs after pyroxene crystals; these are composed of a mixture of talc, chlorite and serpentine. Highly schistose talc-chlorite schists occur on the Allt Riabhaichain. Serpentines with tremolite, chlorite and olivine have also been mapped in Glen Urquhart by Mr. Cunningham Craig.

'A very peculiar dark schistose rock, rich in lustrous biotite, which Dr. Crampton obtained in one of the ultrabasic parts of the Lewisian on the Allt Riabhaichain may perhaps represent some of the *pyroxenites* which are familiar in that formation. It is a pyroxene biotite hornblende schist which contains much pale green, feebly diochroic amphibole, and small grains of bright green pyroxene with imperfect cleavages. A little talc, magnetite and chlorite, and small patches of calcite are also present. The rock is schistose in the hand specimen, and has been very completely metamorphosed from its original state. None of its ingredients is idiomorphic.

'That the whole of the rocks above described are igneous is evident from their bulk composition, and the paragenesis of their minerals. They form a complete and continuous series parallel to the granites, tonalites, diorites, gabbros, and peridotites of plutonic origin. This conclusion is not affected by the fact that some of them may represent the granitic, doleritic, or ultrabasic veins and dykes which intersect the Lewisian gneiss. The great diversity of rocks which may occur in a single small outcrop is also significant. A small hand specimen may yield three or more micro-slides which might be relegated to different groups. These are essential features of the Lewisian gneiss as they have been described by all geologists who have investigated it.

'The Lewisian, though in one sense a definite entity, is when closely examined a great complex embracing many different types and structures, and having, no doubt, a long and intricate history. But this complexity repeats itself in these inliers and is equally conspicuous in them. Of the Lewisian rocks which lie to the west of the Moine thrust only one important group is absent, the pyroxene granulites rich in hypersthene. No hypersthene has as yet been detected in the gneisses of the inliers. Epidote is more common in the latter rocks than in the main Lewisian masses, but even in these it is by no means infrequent. Orthite is certainly usually common in the rocks in question, but it is also present in certain Lewisian gneisses from the Loch Maree area. Veins consisting mainly of orthite have lately been reported from the Lewisian rocks of the Glenelg district.

Moreover, the amount of epidote is known to increase as the unconformable junction between the Archæan and the Torridonian is approached, and it is believed by the geologists who have mapped the ground that Dr. Peach was right in suggesting that the Lewisian inliers occupy their present position, not on account of thrusts or dislocations, but are upfolds of a platform on which the Moines were unconformably laid down.

'*Schists and Gneisses of Sedimentary Origin* (Paragneisses). Rocks of the above groups occur in most of the Lewisian inliers. Pure marbles have not as yet been met with, but granular, crystalline, rather coarse-grained rocks consisting principally of calcite with considerable amounts of pale green augite (malacolite), pale green or colourless hornblende (tremolite), and nearly white uniaxial biotite (or phlogopite) are frequent (*Cipolins*). The commonest accessories are sphene, epidote (and zoisite), iron oxides, quartz, untwinned or simply twinned alkali felspar (including albite), apatite and zircon. By a diminution in the amount of calcite, these pass into tremolite and malacolite rocks. They have mostly a massive rather than a schistose structure.

'Certain pale yellow epidosites, which occur along with the calc-silicate bands in the inliers, may belong also to this group of altered sediments. They consist, as above mentioned, of epidote, augite and quartz, with felspar and sphene. The epidote is pale yellow, the pyroxene pale green, and they are often not easy to distinguish from one another. Calcite appears in small quantity in some of these rocks. The felspar is mostly untwinned alkali felspar.

'Another interesting group of calc-silicate rocks contains scapolite. The best example yet obtained in the Scardroy district comes from Allt Coire Dubh, in the ground mapped by Mr. Hinxman. It is a grey, fine-grained, banded rock, like a fine gneiss. Its principal ingredients are scapolite, augite, and hornblende. The pyroxene is granular and nearly colourless but quite anidiomorphic. Pale green hornblende is nearly equally common with the augite. Its crystals also are irregular and its pleochroism not strong. Scapolite is very frequent both in a fresh and in a weathered condition. It forms small grains rarely showing traces of crystalline form, and with the characteristic tetragonal cleavage well marked. When it decomposes it becomes turbid and between crossed nicols the bright colours and simple structure of the original mineral are replaced by a mosaic of pale grey. It has been converted into a mineral with lower double refraction, lower refractive index and biaxial character. Careful examination shows that the new mineral is alkali felspar. Primary felspar, mostly oligoclase, occurs also in the rock, but is always perfectly fresh and clear, while the secondary felspar is turbid and cloudy. Moreover, the primary felspar forms simple grains of rounded shape, the new felspar forms pseudomorphs after scapolite, having the external shape of the original mineral but composed of a number of small grains with indefinite orientation and very irregular boundaries. This method of decomposition in scapolite has long been known in large crystals, as for example in the albite pseudomorphs after scapolite from Krageroe, in Norway, but does not seem to have been hitherto recorded in the smaller scapolite crystals of rocks. Biotite and sphene are also present in the sections and apatite seems to be exceptionally abundant.

'It may be noted also that in the limestone of Gortally, Glen Urquhart, scapolite has long been known to occur.

'There are also dark *muscovite biotite schists* well foliated and containing small garnets, quartz, oligoclase, albite and iron oxides. These rocks are not distinguishable from certain phases of the muscovite biotite schists of the Moines. Another group of paragneisses includes highly quartzose *muscovite schists*, free from biotite, and approaching quartz schists. In addition to quartz and muscovite they contain many grains of yellow epidote, a little zircon and iron ores, but little or no felspar.

'*Kyanite* occurs in a muscovite biotite schist or fine grained gneiss, which Mr. Cunningham Craig obtained at Gortally on Glen Urquhart. It is abundant at this locality and forms blue, bladed crystals nearly half an inch in length. Still more important is the presence of a *graphite schist* with crystals of *andalusite* on An Cruachan. It is a dark grey, highly schistose rock which stains the fingers and readily marks paper. The microscopic section shows scaly graphite, pale brown biotite, quartz, oligoclase, iron ores and granular sphene. A little muscovite appears also in the more quartzose folia. The garnet takes the form of small crystals arranged in streaks or folia parallel to the banding of the rock. It has often a weak double refraction and seems to be decomposing into quartz and chlorite. Andalusite occurs in numerous large colourless crystals, almost free from enclosures. Their outlines are irregular. This rock is evidently a contact product.

'The igneous gneisses of the Lewisian inliers are sharply distinguished from the Moine rocks by the fact that these latter are, in a vast majority of cases, clearly altered sediments. Many of them are highly quartzose (psammitic gneisses), others are full of biotite (pelitic gneisses and schists). Only a few of the acid muscovite biotite gneisses of the Lewisian inliers at all resemble in composition the common rocks of the Moines. In structure there is also a marked difference, though this is not easy to describe in words. In particular, the very perfect round-grained texture, so typical of vast numbers of Moine gneisses, does not show itself in the Lewisian rocks. Even the hornblende schists of the latter group are distinguishable as a rule by certain minor characteristics from the epidiorite sills intrusive into the Moine. Above all, the Moine formation is restricted to a comparatively small number of rock types; the Lewisian is richly diversified, and most of its members have no correlates in the Moine Series.

'Similarities in structure and composition might be expected to be greatest in the sedimentary rocks of the two formations; and this is undoubtedly the case, especially in the mica schists, which often cannot be distinguished from one another. But in the Moines calcareous sediments are rare; and no marbles or cipolins have been observed in them where they are typically developed. Such rocks, however, are a characteristic part of the Lewisian in certain areas (Glenelg, Loch Maree, &c.). If confirmatory evidence were required as to the Lewisian age of these inliers, none better could be adduced. Graphite also is foreign to the Moine rocks, but not rare in the Loch Maree series.

'The kyanite gneisses and andalusite schists are of special interest. Similar kyanite-bearing rocks occur at Carnmore (Loch Maree), but andalusite is not known at that locality. This may perhaps be explained by the known tendency of andalusite to change to kyanite under certain conditions of metamorphism. It has long been supposed that the paragneisses of the Loch Maree series may possibly represent some of the sedimentary rocks into which the Lewisian orthogneisses were intruded. This seems to be the most feasible explanation of the occurrence of andalusite schists in association with the orthogneisses of Lewisian type in the An Cruachan inlier. In any case the analogy with the Loch Maree succession is complete.

'The presence of this sedimentary formation distinct from the Moines and underlying them also debars us from supposing that the Lewisian orthogneisses are intrusive into the Moine rocks themselves. Masses of "older granite", highly sheared and gneissose, are known (Garve, Càrn Chuinneag, &c.) to penetrate the Moines and to produce various kinds of hornfelsed rocks, andalusite and kyanite schists, from their more argillaceous members. But these intrusions bear little resemblance to the Lewisian orthogneisses either in the field or under the microscope, and the rocks they are injected into are quite distinct from the marbles, calc-silicate rocks and graphitic schists of the inliers. These facts remove any doubt that may cling to the interpretation of the junction between the two formations, for there are evidently *two* sedimentary series, differing widely in essential characters. The lower of these rests upon and has been contact altered by some part of the great Lewisian orthogneiss, but the Moine gneisses show no such changes as they approach their boundary lines. The Lewisian sediments are sometimes present, but more frequently are absent in the inliers. If they were the original overlying mass into which the Lewisian orthogneisses or the latest members of that group were injected they must have been partly removed by denudation before the Moines were deposited.'

Summary. The evidence indicating the probable unconformity between the Moine Series and the inliers of Lewisian Gneiss may thus be summarized:

(1) The dominant members of the inliers of Lewisian Gneiss east of the Moine Thrust are gneisses of igneous origin (orthogneisses) resembling types in the Lewisian Gneiss areas west of the belt of post-Cambrian complication in the counties of Sutherland and Ross, while the characteristic members of the Moine Series are schists and gneisses of sedimentary origin.

(2) The orthogneisses of the Lewisian inliers have produced, in

some instances, contact metamorphism of the Lewisian paragneisses of sedimentary origin, but not of the adjoining Moine sediments.

(3) At a few exceptional localities a conglomerate has been recorded at the base of the Moine rocks where they are in contact with the inliers of Lewisian Gneiss.

(4) Along the line of junction between the Moine rocks and the Lewisian inliers different bands of Lewisian orthogneisses and paragneisses come in contact with the Moine schists, and different zones in the Moine Series abut against the Lewisian rocks.

TARSKAVAIG-MOINE SCHISTS

West of Moine Thrust in Skye

The Tarskavaig-Moine schists, as previously stated, were grouped by C. T. Clough with the Moine Series though carried westwards by displacements below the horizon of the Moine Thrust. Peach laid special emphasis on the evidence furnished by this thrust mass in support of his hypothesis that the members of the Moine Series are altered representatives of the Torridon Sandstone. He held that they mark an intermediate stage in the development of the metamorphism characteristic of the Moine Series. This evidence is here briefly given.

These rocks occupy a small area in the southern part of Sleat, in Skye, between Tarskavaig Bay on the west coast and Calligary on the eastern shore. The rocks overlying the Tarskavaig thrust-plane consist of sheared Lewisian Gneiss and altered sediments, representing what were originally false-bedded grits or sandstones with groups of sandy shales and occasional thin calcareous lenticles. They are supposed to have had some resemblance to the Diabaig Group of the Torridon Sandstone with certain lithological differences. For example, no trace of the epidotic conglomerates has been observed at the base of the altered sediments in the Tarskavaig thrust mass, although these conglomerates are a characteristic feature of the Diabaig Group in Skye. Clough[1] accounts for these divergent types in the following manner:

> 'If they represent an altered Torridonian formation they must have been pushed from an area in which the conditions of deposition somewhat differed from those indicated by the known Torridonian groups elsewhere, and in which also the rocks were more altered than farther to the north-west. The Tarskavaig-Moine schists are less altered than the Moine schists on the east side of the Moine Thrust, but in their relations to the Lewisian Gneiss these two sets of schists closely resemble one another.'

[1] *Geological Structure of the North-West Highlands* (1907), p. 590.

The altered sediments in contact with the Lewisian Gneiss in this thrust mass are composed chiefly of phyllites with some siliceous schists, succeeded by an alternating series of siliceous schists and phyllites. Thin sandy streaks and calcareous seams with clastic grains are interleaved in the phyllites. Minute flakes of white mica give a lustrous appearance to these fine-grained sediments. In places the phyllites have a spotted appearance due to aggregations of black mica or chlorite, evidently of secondary origin, and certain bands also contain garnets. These spots are supposed to have been developed by contact-metamorphism near some igneous intrusion earlier than the movements, but later than the regional metamorphism. As the mica flakes in these spotted schists are later than the granulitic constituents, Clough[1] inferred that 'these schists were granulitized and essentially in their present condition before the thrusts took place. If this conclusion be admitted, the differences in extent of metamorphism between the Tarskavaig-Moine schists below and the Moine schists above the Moine thrust existed prior to the thrust.' He supposed that these rocks were pushed from an area in which the metamorphism increased in a south-easterly direction.

Next in order come the schistose grits which occupy the greater part of the area. Their prominent constituents are quartz and felspar which have undergone much alteration. The larger quartz pebbles have been drawn out into parallel streaks, and, like the red microcline felspar, show partial granulitization. Flakes of white mica appear on the schistose planes. Small grains of epidote are of common occurrence, and are sometimes so abundant as to give a greenish-yellow colour to the rock.

Thin segregation veins, composed of quartz, some red felspar, chlorite, and occasionally some carbonates, traverse the phyllites and schistose grits.

In the northern part of the area occupied by this thrust mass, the Tarskavaig-Moine schists (𝔪, Fig. 20) have been folded into a syncline, the axial planes being inclined to the ESE. They have been driven westwards across the folded Beinn na Seamraig Grits (t^{III}) and Kinloch Beds (t^{IV}) belonging to the Diabaig Group of the Torridon Sandstone, the component members of these groups being almost unaltered. At the eastern limit of the section (Fig. 20) the position of the Moine Thrust is indicated, overriding the Tarskavaig displacement.

Farther south-east in the Sleat peninsula two displacements intervene between the Tarskavaig and Moine thrusts. These are termed the

[1] *Geological Structure of the North-West Highlands* (1907), p. 619.

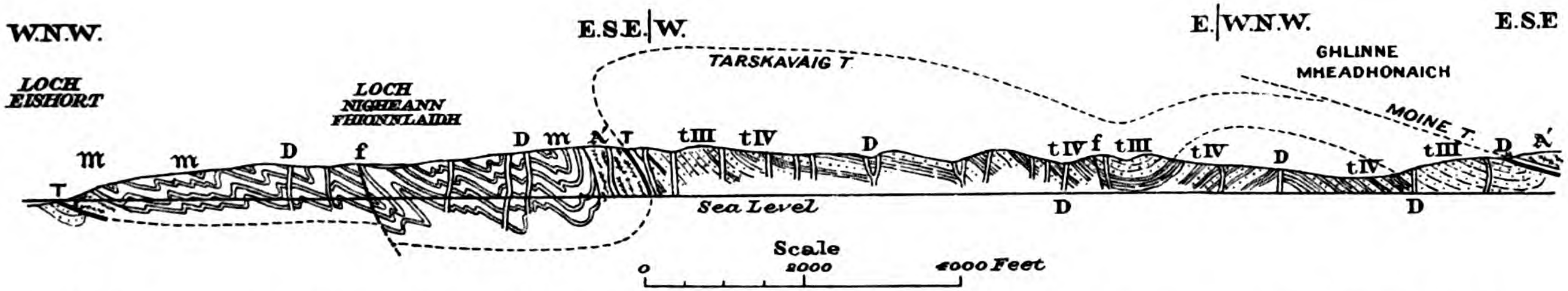


FIG. 20. Section across Tarskavaig Thrust Mass in Sleat, Skye. A′ Lewisian Gneiss. t^{III} Beinn na Seamraig Grits and t^{IV} Kinloch Beds of Diabaig Group of Torridonian. m Tarskavaig Moine Schists. D Tertiary Intrusions. T Thrust. f Fault. (*After C. T. Clough in 'N.W. Highland Memoir', Fig.* 65.)

Caradale and Lamerscaig thrusts, and the materials in the thrust masses consist of sheared gneiss, sandy phyllites, and siliceous, granulitic schists.

MOINE SERIES EAST OF MOINE THRUST

The evidence obtained by the Geological Survey regarding the rocks overlying the Moine thrust-plane will now be briefly indicated.

Narrow Belt above Moine Thrust-plane between North Coast of Sutherland and Skye. The zone of mylonites occurring either above, or in association with, this plane is typically developed on the east side of Loch Eireboll (Geol. Surv. Sheet 114), where they were first observed and named by Lapworth. The various stages in the deformation of the acid and basic gneisses and pegmatites and in the production of striped, green and pink mylonites are clearly displayed. Lenticles of rolled-out quartzite appear, which may belong to the basal division of the Cambrian system. Above these mylonized types come frilled, green schists ('oyster-shell' rock) resembling phyllites, which are succeeded by the typical granulitic quartz-schists and garnetiferous muscovite-biotite-schists of the Moine moorland. The successive bands of rock have been dragged into general parallelism with the Moine thrust-plane, the strike of the schists being NNE. and the dip ESE. at comparatively low angles. But on the east slope of Beinn Thutaig—a hill two miles east from the outcrop of the Moine Thrust—the siliceous granulites and the garnetiferous pelitic schists are folded along axes trending WNW. and ESE., thus producing fine examples of rod or 'mullion' structure.

When this belt is traced southwards to the heights round Meall Horn (Geol. Surv. Sheet 108), the zones of mylonite and green schist are there found above this plane of disruption, followed by siliceous schists and mica-schists, both charged with garnets. Near the head of Loch More the pelitic bands of the Moine Series are represented by phyllites with small garnets, and pebbles are recognizable in the quartz-granulites.

Between Loch More and Gorm Loch More north of Ben More Assynt (Geol. Surv. Sheet 108) the mylonites are traceable, overlain by a group of much puckered (Stack) schists. The latter are fine-grained, the laminae being intensely contorted along axial planes dipping east, east-south-east or north-east. Small pegmatites, about an inch thick, which are not granulitized are of common occurrence in this group. An interesting feature is the presence in these strata of planes, resembling thrust-planes and nearly parallel to the thrusts in the Cambrian rocks to the west. In some instances, a layer of breccia lies along these planes, the fragments having been derived from the adjoining schists, both showing the same grade of metamorphism.

Next in order above the Stack schists come the siliceous granulites of uniform petrographical character, containing thin pegmatites, usually parallel to the foliation of the thin bands in which they occur. North of Gorm Loch More this group is traversed by igneous intrusions, partly granitic and partly composed of hornblende and black mica. They occur in the form of sills, bosses, and dykes, and show more or less foliation in the large exposures. The granitic intrusions have common foliation planes with the schists and show lines of stretching almost in the same direction as those in the schists.

An important feature in the Assynt area is the number of intrusive igneous sheets occurring in the rocks not far above the Moine thrust-plane, which resemble some of the igneous intrusions in the Cambrian strata to the west, and have a common foliation with the Moine schists. Thus in the area south-east of Ben More Assynt (Geol. Surv. Sheet 102), in the tributaries of the River Cassley, the mylonitic zone is succeeded by siliceous granulites and corrugated mica-schists, all showing extreme deformation. A thin sill, regarded by Sir J. S. Flett as a sheared kersantite, appears in these rocks, both having common foliation planes. East of Loch Ailsh the mylonized types are traversed by several thin sills of sheared porphyrite, containing abundant porphyritic felspars and biotites with some quartz. About a mile to the south of that loch, numerous foliated intrusive sheets, resembling some of those in the Cambrian strata to the west, are found in the rocks above the Moine thrust-plane.

In all these localities the strike of the mylonized and granulitized rocks coincides with the strike of the Moine Thrust. Eastwards, however, from the outcrop of this great line of disruption, along both sides of the Oykell valley, there is a remarkable development of rod or 'mullion' structure. This is perhaps the finest example of this structure in the Moine area in the North-West Highlands, and is due to a double system of folding, as already indicated, developed by the post-Cambrian movements.

In the southern border of Assynt in the Knockan Burn (Geol. Surv. Sheet 101), not far above the Moine thrust-plane, a thick sheet of granitic rock runs along the foliation planes of the slightly altered schists. One specimen of the latter is a mylonized arkose, resembling sheared Torridon Sandstone. The sill associated with it contains phenocrysts of orthoclase, plagioclase and microcline, partly granulitized. Again at Leckmelm on the north shore of Loch Broom south-east of Ullapool, bands of foliated porphyrite occur in platy mica-schists of Moine type, and, according to Teall, resemble the oligoclase-hornblende-porphyrite in the thrust masses in Assynt.

The bands of mylonized rocks on both sides of Loch Broom form a narrow belt and are overlain by the typical flaggy, siliceous granulites with partings of biotite-schist, both charged with small garnets. The latter type contains augen of quartz and felspar which may represent original clastic grains. In the Rhidorroch Forest, six miles east of Ullapool (Geol. Surv. Sheet 101), schistose pebbly grits occur with the siliceous schists, the pebbles of quartz and felspar measuring a quarter of an inch across. In some parts of the area white and pink segregation veins and pegmatites appear in the schists. The general dip of the strata is ESE. at angles varying from 10° to 20°. Lines of stretching or friction lines trending WNW. or north-west, produced by differential movement of the constituents, have been observed in these rocks. While mapping the area south of Loch Broom, W. Gunn inferred from the evidence exposed on the cliffs east of Dundonnell that altered Torridon Sandstone had entered into the composition of the Moine schists.

South of Kinlochewe, a narrow belt of rocks has been traced for several miles, showing structures intermediate between the deformed Torridonian sediments to the west and the crystalline schists of the Moine Series to the east (Geol. Surv. Sheet 82). They are well displayed in Cnoc Daimh Burn, where they consist of platy schists resting upon highly mylonized Lewisian Gneiss, the latter indicating a line of movement. They are composed of quartz, felspar, and sericitic mica, small scales of brown mica, and minute grains of epidote. Teall states [1] that 'under a low power this rock resembles a sandy shale, but under a high power the structure is more allied to that of a crystalline schist. It is difficult to avoid the conclusion that this is one of the sandy shales of the Torridonian system.' Further down the stream the platy schists are overlain by fine-grained siliceous schists with 'eyes' of felspar. Teall notes that the rock appears to be 'a sheared epidotic grit, and, like the previous finer-grained rocks, is intermediate in structure between a normal sediment and a true crystalline schist'. The position of the Moine Thrust truncating these intermediate types is concealed by the alluvium of the Cnoc Daimh Burn. Eastwards, there is a great development of the siliceous granulites of the Moine Series, containing at one locality a band of quartz-magnetite-schist.

In the Loch Carron district the grade of metamorphism of the rocks above the Moine thrust-plane is comparatively low on the west side of that loch (Geol. Surv. Sheet 82). Slates and phyllites occur

[1] See 'Geological Structure of the North-West Highlands', *Mem. Geol. Surv.* (1907), pp. 554, 555, where a detailed description of this section is given.

there with siliceous types, which include pebbly arkoses and calcareous grits not wholly granulitized. In the islands in the middle of the loch quartzose flagstones are to be found, the quartz and felspar being partly granulitized. On the east side of the loch the alteration is more pronounced. Muscovite-biotite-schists with garnets are there associated with flaggy, granulitic, quartzose schists with thin micaceous partings, traversed by quartzo-felspathic veins. These varieties occur in folds of Lewisian Gneiss inliers. Eastwards the metamorphism increases as shown by the coarser crystallization of the constituents of each successive zone, and of the veins which sometimes appear as pegmatites with large flakes of muscovite showing no trace of deformation.

In Skye the schists overlying the Moine disruption are to be seen on the shore north and south of Isle Ornsay (Geol. Surv. Sheet 71), where they show, as already stated (p. 171), a higher grade of metamorphism than that of the Tarskavaig-Moine schists west of this line of movement. In the schists above the plane, clastic grains are not readily found. The granulitic mosaic is more clearly defined. The flakes of muscovite on the foliation planes are larger than those in the Tarskavaig-Moine schists and are associated with flakes of biotite and occasionally with garnets. Veins of quartz and felspar are larger and more abundant. On the mainland east of Kyle Rhea the rocks next the Lewisian Gneiss inlier are typical granulitic siliceous flagstones.

Summary. The following conclusions may be drawn from the evidence presented in the foregoing pages regarding the rocks forming a narrow belt above the Moine thrust-plane:

(1) The zones of mylonite and green schist possess structures which are directly due to the post-Cambrian movements.

(2) Deformed grits resembling Torridonian arkoses occur above this plane in the Assynt district, south of Loch Broom, and at Loch Carron.

(3) Sills of granitic materials and of porphyrite, resembling some of the intrusive granites and porphyrites in the thrust masses in Assynt, occur in the Moine schists in the Assynt region and near Ullapool.

(4) The grade of metamorphism along the Moine line of disruption for a distance of 100 miles is comparatively low but increases eastwards from that plane.

(5) The mylonites, green schists, phyllites, and deformed grits are succeeded eastwards by typical holocrystalline schists of the Moine Series.

Central Ross-shire Area. The detailed mapping by the Geological Survey of the area extending from the Moine Thrust eastwards across Central Ross-shire (Geol. Surv. Sheets 82 and 83) has led to the subdivision of the members of the Moine Series into the following groups, which are given below in descending order:

Upper Siliceous Group	5. Semi-pelitic schists; fine-grained quartz-biotite-granulites. 4. Massive, siliceous granulites, often highly felspathic, with pebbly bands. 3. Flaggy, siliceous schists with thin partings of mica-schist.
Pelitic Group . .	2. Garnetiferous muscovite-biotite-gneiss or schist.
Lower Siliceous Group	1. Flaggy, very siliceous schists.

This classification is based partly on the sequence of the lithological zones above the inliers of Lewisian Gneiss, and partly on the pitch of the folds exposing the successive layers. Local variations occur in certain districts and some examples appear of the overlap of the lower by higher members of the series, the latter resting directly upon the Lewisian rocks.

The siliceous granulites of the Lower Siliceous Group (1) sometimes contain pale-green mica and small pale-coloured garnets. Epidote occurs in bands in contact with the Lewisian Gneiss. In the area west of Loch Luichart (Geol. Surv. Sheet 83), the upper portion of this group is often massive and some beds are pebbly and calcareous, while the lower part is composed of highly quartzose flags with thin intercalations of mica-schist.

The overlying Pelitic Group (2) is one of the characteristic types of the series and has proved of special importance in interpreting the stratigraphy of this district. Where typically developed the rock is a coarse, flaky gneiss, containing large plates of muscovite and biotite with knots and lenticles of quartzo-felspathic material along the planes of foliation. With the disappearance of these lenticles, the type passes into flaggy muscovite-biotite-schist. Garnets are abundant, occurring in idiomorphic crystals and in aggregates often deformed by movement. Bands of kyanite-gneiss occasionally appear in this group, as for example, in the Erchless Forest, about nine miles WSW. of Beauly, where the kyanite, associated with quartz, garnet, and biotite, forms aggregations that project on weathered surfaces.

The lowest member (3) of the Upper Siliceous Group is composed of semi-pelitic schists, splitting into thin flags, termed Moine Flags. The rocks are highly sheared, but the bedding is defined by thin intercalations of mica-schist. They evidently represent a transitional phase of sedimentation between the underlying pelitic gneiss (2) and the overlying massive granulites (4). The latter frequently show the original planes of bedding marked by lines of heavy minerals; they contain original clastic grains of felspar, and in some localities become pebbly. From their mode of weathering they form conspicuous features in the great corries in Central Ross-shire. The semi-pelitic granulites of the highest subdivision (5) are found in typical development in the Carron and Monar synclines.

The complicated system of folding affecting both the rocks of the Lewisian inliers and the members of the Moine Series throughout this extensive area is illustrated by the accompanying horizontal section[1] (Fig. 21).

The position of the Moine thrust-plane is shown at the western limit of this section at Jeantown, Loch Carron, where it is overlain by siliceous schists, phyllites and calcareous grits in a low grade of metamorphism. East of the loch the Lewisian rocks are exposed in several compound flexures in the Attadale anticline, with infolds of garnetiferous muscovite-biotite-gneiss (2), the lower siliceous group not being represented. Between the Attadale River and Beinn Dronaig the various subdivisions of the Upper Siliceous Group are arranged in a compound syncline (Carron syncline), the strata on the western limb dipping ESE. in normal sequence, and those on the eastern limb in inverted order. On the crest of the dome-shaped arch of Beinn Dronaig there are small exposures of the Lewisian rocks flanked by the Lower Siliceous granulites (1). These are succeeded by a wide development of the flaky Pelitic Gneiss (2), which rises from beneath the members of the Upper Siliceous Group in the Carron syncline on the west and plunges below the same rocks in the Monar syncline on the east. Eastwards on An Cruachan the Lewisian Gneiss reappears in a core of the denuded anticline, succeeded by schists belonging to the Upper Siliceous Group, thus furnishing a striking instance of the overlapping of the two lower groups of the Moine Series, at this locality. These Upper Siliceous granulites are truncated by the Strathconon fault which brings them in contact with another inlier of Lewisian Gneiss exposed for more than a mile in the line of section. Still farther east, near Sgùrr na Lapaich, Lewisian rocks forming the south-west continuation of the Glen Strath Farrar inlier come to the surface, and are overlain by Pelitic Gneiss (2) which covers the greater part of that mountain in a complex system of isoclinal folds.

Area around the Igneous Masses of Càrn Chuinneag and Inchbae, North-East Ross-shire (Fig. 23, p. 194). As already indicated (p. 147),

[1] 'Geology of Central Ross-shire', *Mem. Geol. Surv.* (1913), p. 74.

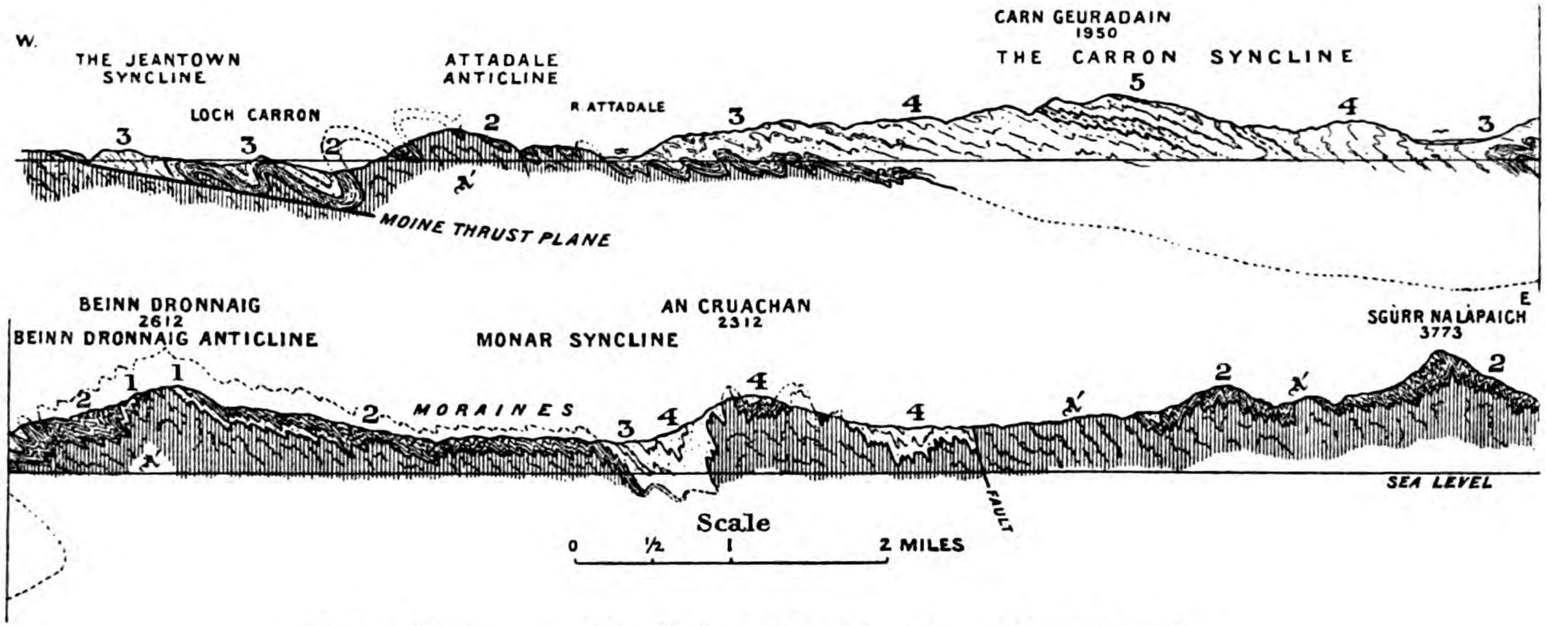


FIG. 21. Section across Moine Schists and Lewisian inliers of Central Ross-shire.

Moine Series:
- 5. Semi-pelitic schists.
- 4. Massive siliceous granulites.
- 3. Flaggy siliceous schists.
- 2. Pelitic gneiss.
- 1. Lower siliceous schists.

𝔄′ Lewisian Gneiss. ⩪ Raised Beach. ~ Alluvium.

(*After 'Geol. Central Ross-shire', Fig.* 8.)

this district (Geol. Surv. Sheet 93) furnishes remarkable evidence bearing upon the original character of the members of the Moine Series in contact with these igneous masses, which were injected before the regional metamorphism of the sediments. Reference will be made in the sequel (p. 193) to the altered rocks in the aureole of the Càrn Chuinneag plutonic complex and their passage into Moine schists by subsequent dynamic movements.

The various subdivisions of the Moine Series established in this area are given below in descending order : [1]

Upper Pelitic Group	4. Pelitic mica-schist and hornfels.
Upper Siliceous Group	3. Flaggy and massive quartz-biotite-granulites, with pebbly bands on certain horizons.
Lower Pelitic Group	2. Garnetiferous muscovite-biotite-schist.
Lower Siliceous Group	1. Highly quartzose, flaggy granulites.

These subdivisions are arranged in a compound synclinal fold with its major axis trending north-east and south-west, the Càrn Chuinneag igneous mass occupying the centre of the great flexure (Fig. 22).

On the north-west limb is an ascending sequence from the Lower Pelitic Group (2) to the Upper Pelitic Group (4) in contact with the igneous intrusion of Càrn Chuinneag. On the south-east limb, in the line of section, the four groups appear in inverted order owing to the intense isoclinal folding of the rocks, the axial planes dipping at various angles to the south-east.

The lithological characters of the two lowest groups (1, 2) in this area closely resemble those in the corresponding groups in Central Ross-shire, but the granulites of the Upper Siliceous Group (3) on both sides of the Càrn Chuinneag intrusion have a more marked development of well-preserved pebbles indicating their sedimentary origin. On the south-east limb they appear at Lochan Gobhlach, about four miles west from the head of Loch Glass, and near Càrn Beag north of Loch Morie. On the north-west limb the pebbly bands have been traced from Beinn a' Chasteil by Carn Feur-lochain to beyond Dunan Liath—a distance of about six miles. Pebbles weathered out of the rock form, in places, a thin gravelly layer on the flat top of Beinn a' Chasteil.

Among the pebbles, Flett has identified quartz probably derived from quartz veins, felspar referred to microcline, albite or orthoclase, quartzo-felspathic granulites resembling the fine psammitic gneisses of the Moine Series, graphic granite, and one schistose fragment which may be a hæmatite mica-schist. Some of the pebbles are not much deformed, others are elongated and flattened like ribbons. The

[1] 'Geology of Ben Wyvis, Càrn Chuinneag, Inchbae, &c.', *Mem. Geol. Surv.* (1912), p. 13.

matrix of the conglomeratic schist is a granulitic aggregate of quartz, felspar, and mica, usually siliceous, and often rich in iron oxides, zircon, garnet, epidote, orthite, and other heavy minerals. The matrix of schist cementing the pebbles is rendered almost opaque by the abundance of iron oxides, principally magnetite. Their clastic origin is clear from their distribution in bands which represent original bedding planes.

The belt of Upper Pelitic schist and hornfels (4) has been traced for a distance of eighteen miles round the margin of the Càrn Chuinneag igneous intrusion varying in width from half a mile to a mile. Consisting mainly of sandy shales which have been hornfelsed by the granite, these altered sediments have preserved their original bedding planes and the clastic grains are distinct. No less important is the occurrence of sun-cracks and ripple-marks on the surfaces of the bedding planes. The same beds appear as hornfelsed shales with no trace of foliation next the granite, and, when followed along the strike, pass into foliated mica-schist and form integral members of the Moine Series.

A characteristic feature of the Moine Series in this area is the occurrence of bands of zoisite-granulite and of zoisite-hornblende-gneiss. Two types have been recognized by Flett;[1] 'in one the zoisite occurs only in minute grains, invisible to the unaided eye, and the rock has much of the appearance of the nearly massive quartzo-felspathic granulites; in the other the zoisite forms long, grey blades running through the matrix, and conspicuous on weathered surfaces. They have often no definite orientation parallel to the foliation.' He also refers to the analysis of a specimen of garnetiferous-zoisite-hornblende-granulite from this area which shows that it was originally a siliceous marl.[2]

Tourmaline also is found in the Moine Series in this district. Numerous crystals, one to two inches in length, have been observed by Peach in siliceous granulites, intercalated in the pelitic gneiss near Loch Luichart.

Fannich Mountains Area, Ross-shire (Plate XV, 1). The order of succession of the strata in this region (Geol. Surv. Sheet 92) varies to some extent from that occurring in the tract already described between Kinlochewe and Sgùrr na Lapaich in Central Ross-shire. The rocks are arranged in what is believed to be a great recumbent fold with a core of grey, acid gneiss, containing lenticles and bands of epidiorite, epidote-pyroxene-granulite and other basic types, which resemble varieties of Lewisian Gneiss in the west of Sutherland and Ross. From this floor of Lewisian rocks the following sequence of the

[1] Loc. cit., pp. 42–3. [2] Ibid., p. 45.

PLATE XV

1. Sgùrr nan Clach Geala (3,637 ft.), Fannich Forest. Cliffs of foreground are flaggy siliceous schists; summit is garnetiferous muscovite-biotite-gneiss.

2. Folding in siliceous schists, at bridge over Blackwater, 4 m. S. of Inchbae.

VIEWS OF MOINE SCHISTS

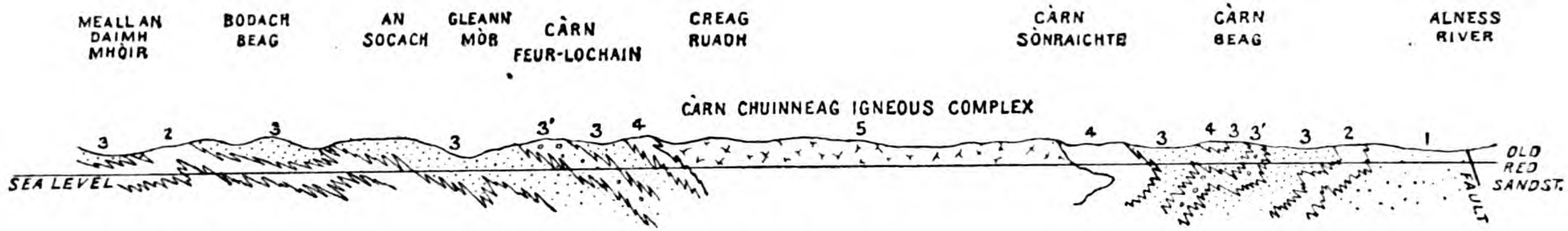


FIG. 22. Diagrammatic section across Càrn Chuinneag Augen Gneiss and associated Moine Schists, Ross-shire. Scale: 1 inch=3 miles. 1–4 Moine Schists: 1 Lower Siliceous Group; 2 Lower Pelitic Group; 3 Upper Siliceous Group; 3′ Pebbly portion of Upper Siliceous Group; 4 Upper Pelitic Group; 5 Intrusive rocks (Augen Gneiss, &c.) of Càrn Chuinneag Plutonic Complex. (*After C. B. Crampton in 'Geology of Ben Wyvis, Càrn Chuinneag, Inchbae', Fig. 1.*)

members of the Moine Series has been adopted by the Geological Survey:[1]

(4) Flaggy, granulitic, quartzose schists with thin bands of mica-schist.
(3) Dark biotite-schist with occasional small garnets (Sgùrr Mòr biotite-schist).
(2) Granulitic, quartzose schist, mainly composed of quartz and felspar (Meall a' Chrasgaid Rock).
(1) Massive, garnetiferous muscovite-biotite-gneiss with thin lenticles of quartzo-felspathic material along the foliation planes. This group overlies and underlies the Lewisian rocks.

The great recumbent fold into which these subdivisions enter is supposed to have an amplitude of several miles. Owing to the excessive denudation of the region, the geological structure is rather complicated, but the relations which the rocks bear to each other are suggestive of fan-structure. Dark biotite-schists (3) have furnished at several localities fine specimens of zoisite-granulite showing conspicuous prisms of zoisite about a quarter of an inch in length on the flat surfaces of the specimens. The quartzo-felspathic lenticles in the Pelitic Gneiss (1) overlying the Lewisian rocks on the south side of the Fannich watershed contain small prisms of tourmaline. On Beinn nan Ramh—a hill SSW. of the head of Loch Fannich—prisms of tourmaline, four to five inches long, were found in pegmatites in pelitic gneiss. These pegmatites are linked with the regional metamorphism of the Moine Series and not with the Newer Granites.

Strath Oykell and Shin Valley Area. In this region, comprising several hundred square miles of ground (Geol. Surv. Sheet 102), the members of the Moine Series present remarkably uniform petrographical characters. The dominant type is a quartz-felspar-granulite with few variations. It is either massive or flaggy, and often shows colour-banding due partly to the presence of mica in adjacent layers and partly to thin seams of dark iron ores or other heavy constituents. Felspar pebbles, up to a quarter of an inch in diameter, with granulitized margins, appear in some of the siliceous flags. Thin micaceous partings separate the flags, and bands of semi-pelitic schists also occur in the series. Epidote is widely distributed in these granulites and garnet is not rare. Garnetiferous muscovite-biotite-schist (pelitic gneiss) occupies a considerable tract near Corriemulzie south of Strath Oykell, which is the northern continuation of the Lower Pelitic Group on the west side of the Càrn Chuinneag plutonic complex

[1] 'The Geology of the Fannich Mountains, &c.', *Mem. Geol. Surv.* (1913), p. 65.

(p. 181). Bands of zoisite-amphibole-granulite are characteristic of the series.

Of special interest are the hornblendic rocks of Durcha type, supposed to be of sedimentary origin, which appear near the croft of Durcha about two miles east of Invercassley, in the Oykell valley. Dr. H. H. Read thus describes the rocks at that locality:[1]

'Among the different types that occur is a coarse dark-green or black rock composed almost entirely of hornblende, the acicular crystals of which show a tendency to lie with their vertical axes in one plane. A slightly different type is one where the hornblendic material is banded with narrow stripes of pale quartzo-felspathic material, and by the increase in the number of such bands the rock takes on a markedly striped aspect. The striping is extremely delicate and persistent and runs parallel with the foliation of the neighbouring granulites. Often on the plane surfaces of the stripes throughout both the quartzo-felspathic and hornblendic portions, there are large bladed crystals of green actinolite up to two inches in length which lie with their vertical axes in the foliation-planes but show no other orientation. A final type is represented by a rock mainly quartzo-felspathic in character but with very regular and persistent bands of hornblende often less than one-twelfth of an inch in thickness.'

He advances the following points in favour of their sedimentary origin:[2]

'They are extremely regular even when exceptionally thin; they appear never to coalesce or to cut across the granulite; there is a gradual passage from hornblende bands to bands with scattered hornblendes, and from these to what has been taken to be Moine granulite; and they sometimes break up into lines of separated hornblende crystals.'

It is suggested that the whole set may be due to the regional metamorphism of marly or chloritic sediments.

An important outcrop of limestone, about twenty feet thick, occurs at Shinness, beside Loch Shin, where it was formerly worked. It is composed of rapid alternations of dark weathering calcite and calc-silicate-rock and is associated with bands of hornblende-schist. The limestone occurs in the midst of quartz-felspar-granulites characteristic of the Moine Series.

Conspicuous examples of the double system of folding in the Moine Series have been recorded throughout this area.

Glen Urquhart to Beauly Firth and Rosemarkie Area. The general type of Moine schists overlying the inlier of Lewisian rocks in Glen Urquhart, and extending north-east to Abriachan (Geol. Surv. Sheet 83), is a very felspathic quartz-biotite-schist or gneiss, with a marked

[1] 'The Geology of Strath Oykell and Lower Loch Shin', *Mem. Geol. Surv.* (1926), p. 144.
[2] Ibid., p. 146.

development of muscovite in some laminae. At some localities, thin bands of garnetiferous-muscovite-biotite-schist containing lenticles of quartzo-felspathic material alternate with finely crystalline siliceous schist.

Farther north, in the tract between Dochfour Hill and Beauly Firth, two types of the Moine Series occur. One is composed of biotite-gneiss, frequently coarse-grained, with knots and lenticles of quartzo-felspathic material along the planes of foliation, the other of fine-grained, flaggy quartz-biotite-granulite. Limestone is exposed at three localities in the schists, one at Rebeg six miles WSW. of Inverness, the second near South Clunes, west from Moniack Burn, and the third at Blairnachenachrie, north by west from Dochfour House. The calcareous zone is to be seen in the Rebeg quarry and in an adjacent rock-cutting which crosses the strike for sixty yards. The limestone is there associated with hornblende-schist, hornblende-biotite-schist, and flaggy granulites like those of the Moine Series.

Sir J. S. Flett[1] has described certain exceptional types in the Moine area, on the shore north-east of the village of Rosemarkie on the north side of the Moray Firth (Geol. Surv. Sheet 84). These include talc-chlorite-biotite-schist, biotite-granulite with rounded grains of quartz and felspar, resembling a contact altered grit in which the clastic structures have not been destroyed, also biotite-granulite, containing a little hornblende. They are traversed by bands of hornblende-schist. He refers to them in the following terms:

'They [microscopic sections] are not in a very satisfactory condition because they are often decomposed, brecciated, and veined with calcite, the result apparently of earth movements and the circulation of water along the Great Glen fault which runs close to this shore. But neither individually nor collectively have these rocks any close resemblance to the ordinary types of Moine gneiss and schist of the East and North of Scotland. There is not one of them which, if it had been collected among typical Moine gneisses, would not have been regarded as anomalous, and, taken together, this series leaves the impression that it belongs to some other formation than the Moine Series or to some division of that formation that is unlike the rest and has a very limited distribution.'

Strath Nairn to Monadhliath Mountains Area. Throughout this wide region (Geol. Surv. Sheets 74 and 84) the rocks have been arranged by the Geological Survey in two divisions, siliceous and pelitic. The siliceous group includes quartz-felspar-granulites and bands of what might be termed quartzite, composed almost wholly of rounded grains of quartz with a small proportion of felspar and

[1] 'The Geology of the Lower Findhorn and Lower Strath Nairn', *Mem. Geol. Surv.* (1923), p. 57.

hardly any mica. The pelitic rocks consist of flaky, garnetiferous muscovite-biotite-gneiss, the garnets occurring as aggregates and idiomorphic crystals. This coarse variety alternates with and merges into flaggy biotite-schist or muscovite-biotite-schist. There is a large development of semi-pelitic schists representing intermediate stages between the siliceous granulites and the pelitic gneiss. Garnetiferous zoisite-granulites have been recorded which occur as siliceous bands among the granulitic biotite-schists or gneisses.

Near the eastern margin of the Moine area, in the valley of the Spey at Inveravon and in the Cromdale Hills (Geol. Surv. Sheets 75 and 84), the members of this series assume a highly quartzose phase. In the latter tract they consist of schistose quartzite, quartz-schists, mica-schists, quartzose and micaceous flagstones, which are holocrystalline and granulitic.

Limestone occurs at several isolated localities, as for instance, above Kincraig House in the Spey valley, where it appears as a white marble with thin beds of greenish calc-silicate-rock, from twenty to twenty-five feet thick. It is associated with fine-grained biotite-muscovite-gneiss, containing thin calcareous layers and bands of hornblende-schist. Again on the west side of the Findhorn valley above Kyllachie House several small outcrops of crystalline limestone and calc-silicate-rock have been observed in the midst of quartz-biotite-granulites, mica-schists, and pelitic gneiss. Not far from the Kyllachie limestone quarry, on the west slope of Càrn na Seanalaich the calc-silicate-rocks are in contact with a band of hornblende-schist. The frequent association of hornblende-schist with the rare exposures of limestone in the Moine Series is worthy of note.

The remarkable feature of this region is the persistence of rock-types which are characteristic of the Moine Series in the counties of Sutherland, Ross, and Inverness. They are holocrystalline schists which seldom show original clastic structures.

Special attention has been directed by the Geological Survey [1] to a group of altered sediments termed the Grantown Series, extending for several miles on either side of Dulnan Bridge. The strata consist of (1) quartzite, (2) fine micaceous granulites, (3) coarsely micaceous gneisses resembling in places the pelitic gneisses of the Moine Series, but differing from them in the occasional presence of graphite, (4) coarsely crystalline limestones and calc-silicate-rocks. The distinctive feature of the coarse pelitic types (3), apart from the occasional flakes of graphite, is the presence in them of kyanite in crystals up to an inch in length, supposed to be due to thermal metamorphism caused by granite not far below the surface. This assemblage is surrounded

[1] 'Geology of Mid-Strathspey and Strathdearn', *Mem. Geol. Surv.* (1915), p. 27.

by the more siliceous type of Moine granulite which comes in contact with several members of the Grantown Series. It is suggested by E. M. Anderson that the flaky gneiss with graphite and the crystalline limestones and calc-silicate-rocks may be an outlier or an inlier of corresponding types of the Dalradian Series of Banffshire.

A prominent feature in this area is the great development of pelitic gneiss, traceable in belts from the basin of the Findhorn to the Monadhliath Mountains. The greater part of the latter range is occupied by representatives of this division. While the strike of the siliceous and pelitic groups is generally north-east and south-west it varies considerably in certain districts owing to the intense folding and overfolding which the rocks have undergone. Thus in the Findhorn basin the pelitic gneiss forms a large ring-shaped outcrop underlain and overlain by siliceous schists. The original order of deposition of these altered sediments has not been determined.

Upper Strathspey to Glen Tilt and Braemar Area. In Upper Strathspey (Geol. Surv. Sheet 64) flaky, garnetiferous muscovite-biotite-gneiss occurs west of Newtonmore, where it forms the southern continuation of the broad belt of pelitic gneiss of the Monadhliath Mountains. In the lower part of the Truim valley near the junction of that river with the Spey narrow belts of similar material are interfolded with quartz-biotite-granulites. Eastwards across the Gaick Forest to the western margin of the granitic mass of the Cairngorm range no belts of pelitic gneiss have been found. The latter area is occupied by a great development of quartzose, felspathic, granulitic gneisses, with a variable quantity of biotite and some muscovite. The folding in places is isoclinal, the folds being generally horizontal with consequent low dips. In the Gaick area, four zones of the psammitic group, based on their lithological characters, were identified by E. H. Cunningham Craig.[1] These types range from thick-bedded quartz-biotite-gneisses with little felspar and hardly any muscovite to finely-banded, pink, felspathic gneisses with less biotite and more muscovite.

The Moine gneisses on the south side of the Grampian watershed between the River Garry above Strowan (Struan) and Braemar are of special interest as they involve problems bearing on their relation to the Dalradian Series.

G. Barrow[2] has examined these rocks in the field, has studied their microscopic characters, and, as already indicated, has concluded that they are identical with the Moine gneisses of the North-West Highlands. The following observations are based on his descriptions.

[1] 'Geology of Upper Strathspey, &c.', *Mem. Geol. Surv.* (1913), p. 45.

[2] 'The Moine Gneisses of the East-Central Highlands and their Position in the Highland Sequence', *Quart. Journ. Geol. Soc.*, vol. lx (1904), p. 400.

The River Garry (Geol. Surv. Sheet 55) exposes an admirable section of the Moine Series, where, with certain exceptions, they consist of flaggy gneisses, averaging six inches in thickness, with an apparently persistent dip to the south-east at an angle of from 20° to 30°. The dominant member is a grey, colour-banded, granular, acid gneiss with brown and white mica in variable quantity. The arrangement of the biotite parallel to the colour-banding and the presence of films of felted dark mica which are always parallel, accentuate the bedded appearance of the flags. Pink-edged gneisses rich in microcline with some epidote or zoisite are also found, together with a highly-micaceous, cross-cleaved type with abundant white mica and biotite or chlorite. While the series as a whole is flaggy, massive varieties also occur. The apparently ascending sequence in the Garry section is regarded as deceptive. The strata are supposed to be repeated by small folds, the longer limb dipping to the ESE.

In the Perthshire portion of the area east of the Glen Tilt igneous complex (Geol. Surv. Sheet 64) the members of the series exhibit some differences from those in the Garry section. There is an increase of biotite in the rocks, and sillimanite is visible in some of the thin micaceous partings. Two types are indicated. The first, weathering with rounded outlines and of a somewhat massive character, contains little microcline and much plagioclase (mostly oligoclase) often fringed with vermicular pegmatite. This variety is succeeded in certain localities by a flaggy phase with abundant microcline and distinct parallel structures. The second type is characterized by the occurrence in it of lenticular structure, due to mechanical deformation, the movement planes being coated with dark mica. From the absence of this structure in the typical grey gneisses it is inferred that the latter were not mechanically deformed before crystallization within the individual bands, though sliding may have taken place along the chloritic partings.

In the Aberdeenshire area west of the Lochnagar granite (Geol. Surv. Sheets 64 and 65) the prevalent variety is a massive, grey, highly-crystalline gneiss with little white mica. Except on one horizon, plagioclase is more abundant than microcline. Three types were described by Teall: the first is a typical, grey granulite, rich in iron ore and zircon arranged parallel with the bedding planes and colour-banding; the second is a band with numerous small, pink garnets; the third is a pink-edged epidotic gneiss containing much microcline.

In the tract bordering the Dee above Braemar, the rocks become highly quartzose, being largely composed of the Central Highland quartzite (Dalradian) interfolded with typical grey and pink banded

Moine gneisses. Again in that part of the Invercauld Forest north of Braemar (Geol. Surv. Sheet 65) the members of the Moine Series are highly quartzose, so that it is difficult to fix the boundary between the Moine gneisses and the Central Highland quartzite, for the latter assumes there a 'Moine-phase'. The typical white margin of the quartzite can be identified at one locality and the adjoining exposures seem to point to the conclusion that the greater part of the quartzose gneiss is composed of the main quartzite (Dalradian).

Barrow thus summarizes his account of the Moine gneisses:

'1. These gneisses are a parallel-banded series of sedimentary origin, usually rich in felspar (largely microcline), and containing dark biotite in variable quantity.

2. The gneisses are thinly-bedded, as a whole; and their structure is essentially parallel, but not lenticular or phacoidal. This parallel structure is in most cases shown by the arrangement of the biotite.

3. Certain types can be recognised again and again throughout the whole area; and their repeated occurrence shows that the whole series is really thin, although by intense folding it simulates a succession of enormous thickness.

4. Although the variation in the typical grey gneisses, as they are traced eastward, is not great, still it is important. Biotite is, on the whole, more abundant; and the highly-micaceous partings become more aluminous, that is, were more of the nature of fine mud originally.

5. A striking feature of the grey gneisses is seen in the films of felted biotite, derived from original, clastic chlorite, and indicating the former bedding-planes. Their presence is highly important, especially when we consider the mode in which the Moine Gneisses end off when traced to the south-east, as it will be seen that they link the gneisses with the Dark Schist, of which the same material was an abundant constituent.

6. Lastly, a considerable mass of highly-quartzose material, which, for purposes of mapping, must be included in the Moine Gneiss, can in the eastern part of the area be shown to be really the Highland Quartzite (in what may be conveniently called a "Moine-phase"), and should be excluded from the group when discussing the origin of the grey gneisses.'

Ardgour and part of Morven, north-west of Loch Linnhe Area. In the tract[1] extending south-westward from Loch Eil across Ardgour to Morven, there is a large development of the psammitic and pelitic groups of the Moine Series. The most siliceous phase consists of quartz-granulites representing very pure sandstones, which have been mapped by the Geological Survey as a distinct zone from the siliceous gneisses of Moine type (Geol. Surv. Sheet 53). The latter are grey,

[1] 'Summary of Progress for 1897', *Mem. Geol. Surv.* (1898), p. 65; for 1898 (1899), p. 40; for 1901 (1902), p. 120; for 1902 (1903), p. 76: 'Geology of Ben Nevis and Glen Coe', *Mem. Geol. Surv.* (1916), p. 84: 'Pre-Tertiary Geology of Mull, Loch Aline and Oban', *Mem. Geol. Surv.* (1925), p. 7.

flaggy, granulitic rocks with felspar, black and white mica, in addition to the quartz, and represent what were originally banded, impure, arenaceous sediments. The prominent member of the pelitic group is a coarsely crystalline muscovite-biotite-gneiss with knots and strings of quartzo-felspathic material. Where these strings disappear and the muscovite is reduced in quantity the rock becomes a biotite-gneiss. An interesting feature of the Moine Series in this region is the occurrence in it of the Ardgour marble, which is closely associated with portions of the Glen Scaddle igneous complex. This marble contains calcite, forsterite, colourless pyroxene, felspar, garnet, sphene and graphite in variable proportions.

Ross of Mull Area. The evidence obtained in the south-west peninsula of the island of Mull regarding the Moine Series is of special importance as it shows the extreme contact-alteration superimposed by the Mull Newer Granite on the Moine schists after their regional metamorphism.

The members of the Moine Series, which here occupy an area of about eleven square miles (Geol. Surv. Sheets 35 and 43), have been described by T. O. Bosworth.[1] The rocks, which strike in a north-easterly direction, include representatives of the psammitic and pelitic groups of the series. The former group consists chiefly of flaggy quartz-felspar-granulites with some thin beds of quartzose mica-schist. In places where coarse-grained types appear their original conglomeratic character is suggested by long drawn-out pebbles. The pelitic rocks are composed mainly of coarse, garnetiferous muscovite-biotite-gneisses alternating with beds of fine, granulitic, micaceous quartzite and some thin bands of calc-silicate-rock. A conspicuous feature of these gneisses is the abundance of quartzo-felspathic lenticles and pegmatites along the planes of foliation, which share in the folding of the schists. The quartzo-felspathic streaks pass into the thin pegmatites. They are clearly older than the Ross of Mull granite as they are cut by the apophyses of that igneous mass.

Many pegmatites and lenticles contain prisms of tourmaline, and two instances are given in which this mineral and kyanite appear in the pelitic gneiss. In one of these cases the variable composition of the pegmatites is shown by the constituents of three examples: (1) quartz and tourmaline; (2) large crystals of kyanite and white felspar with some quartz; (3) white felspar, tourmaline, and biotite. The second instance is no less notable. The rock, consisting of mica-schist with little quartz and felspar, contains black needles of tourmaline, kyanite, staurolite, and prisms of rutile. The minerals at

[1] *Quart. Jour. Geol. Soc.*, vol. lxvi (1910), p. 376; see also 'Geology of Staffa, Iona and Western Mull', *Mem. Geol. Surv.* (1925), p. 23.

these localities are associated with the regional metamorphism[1] of the Moine sediments and have no connexion with the Newer Granite.

Loch Eilde Mòr Area. Crystalline schists of Moine type occur in this area south-east of Loch Linnhe.[2] They have been named Eilde Flags by E. B. Bailey from Loch Eilde Mòr, situated about two and a half miles ENE. from the head of Loch Leven (Geol. Surv. Sheet 53). They consist of flaggy quartz-biotite-granulites with thin intercalations of pelitic schist. In some localities bands of pure quartzite are interbedded in the granulites; in other places, they are massive with occasional bands of garnetiferous, pelitic gneiss. A quartzose pebbly zone, with large pebbles of quartz and felspar, has been observed on both sides of the River Leven east of Allt na h-Eilde. This belt of crystalline schist of Moine type trends north-east, and occurs in the midst of members of the Dalradian Series. Different interpretations of the structural relations between the Eilde Flags and the Dalradian Series have been given by E. B. Bailey and R. G. Carruthers in the Memoir cited.

The Eilde Flags also appear north and south of Fort William,[3] where they consist of quartzo-felspathic flagstones rich in biotite and muscovite. Thin micaceous layers separate the flagstones and reveal their evenly bedded character.

From the description given in the foregoing pages it is apparent that there is an overwhelming amount of evidence pointing to the wide distribution of the characteristic types of the Moine Series throughout those areas in the Highlands which have been mapped by the Geological Survey. This evidence suggests that the various members of the Moine Series belong to one great geological system.

OLDER IGNEOUS ROCKS IN THE MOINE SERIES

The members of the Moine Series are traversed by basic and acid igneous materials, injected into the sediments before the movements that developed the present schistose structures in these sediments, or, in some instances, before the cessation of these movements. Some rare examples of ultrabasic intrusions have also been observed.

Ultrabasic Rocks. In the Loch Naver district of the county of Sutherland several bosses of serpentine[4] penetrate both the siliceous granulites of the Moine Series and the associated striped rocks

[1] See also 'Geology of Colonsay and Oronsay with Part of Ross of Mull', *Mem. Geol. Surv.* (1911), p. 80; 'Pre-Tertiary Geology of Mull, Loch Aline and Oban', *Mem. Geol. Surv.* (1925), pp. 9–16.

[2] 'Geology of Corrour and the Moor of Rannoch', *Mem. Geol. Surv.* (1923), pp. 9–16.

[3] 'Geology of Ben Nevis and Glen Coe', *Mem. Geol. Surv.* (1916), p. 33.

[4] 'Summary of Progress for 1926', *Mem. Geol. Surv.* (1927), p. 65.

composed of alternations of hornblendic, epidotic, and quartzo-felspathic laminae. They are sheared and foliated along their margins.

Basic Rocks. These types occur usually as lenticular bands running along the strike of the schists, and varying from a foot to many yards in thickness. Their sill-like mode of occurrence is apparent in the field, and their intrusive nature is often indicated by their cutting across the bedding planes of the Moine sediments at a gentle angle. In places they have shared in the folding of the rocks in which they occur, and have been severed into knots and short lenticles by the movements. Where the sills have been foliated, the planes of foliation usually coincide with those in the adjoining schists.

The original igneous structures of these basic rocks have been effaced by the metamorphism which they have undergone and they now appear as epidiorites, garnetiferous amphibolites, hornblende-schists, hornblende-biotite-schists or chlorite-schists. Their chief constituents are hornblende, felspar and quartz, with epidote, sphene, iron oxide, apatite and garnet. Flett[1] states that 'these Moine amphibolites are singularly constant in their characters over a wide area of the north and west of Scotland; those that occur in the Ross of Mull are almost identical in composition and structure with those of Eastern Sutherland'.

These basic intrusions are not equally distributed throughout the Moine area. In some districts they are rather numerous; in others they are rare. Thus in Easter Ross, between Loch Luichart and the west margin of the Old Red Sandstone belt at Contin (Geol. Surv. Sheet 83) they form prominent features in the siliceous granulites and pelitic gneiss. In that region they have shared in the intense plication of the schists, and sometimes appear as lenticles along the strike suggesting that they are disrupted portions of once continuous sills. On the other hand, there are comparatively few examples of this group in the Moine area in Strathspey, in Lower Findhorn and Lower Strath Nairn.

Acid Rocks. By far the most important of the older acid igneous intrusions in the Moine area are those of Càrn Chuinneag and Inchbae in Easter Ross-shire (Geol. Surv. Sheet 93), to which reference has already been made. A striking description of these igneous masses, of the metamorphic aureole in contact with them, and of the passage of the hornfelsed rocks into Moine schists has been given by Clough, Crampton, and Flett.[2]

The Inchbae mass, situated in the midst of the siliceous granulites,

[1] 'Geology of Central Ross-shire', *Mem. Geol. Surv.* (1913), p. 78.
[2] 'The Augen Gneiss and Moine Sediments of Ross-shire', *Geol. Mag.*, Dec. V, vol. vii (1910), p. 337.

is about five miles long and about two miles broad, while the Càrn Chuinneag intrusion is twelve miles in length and from three to five

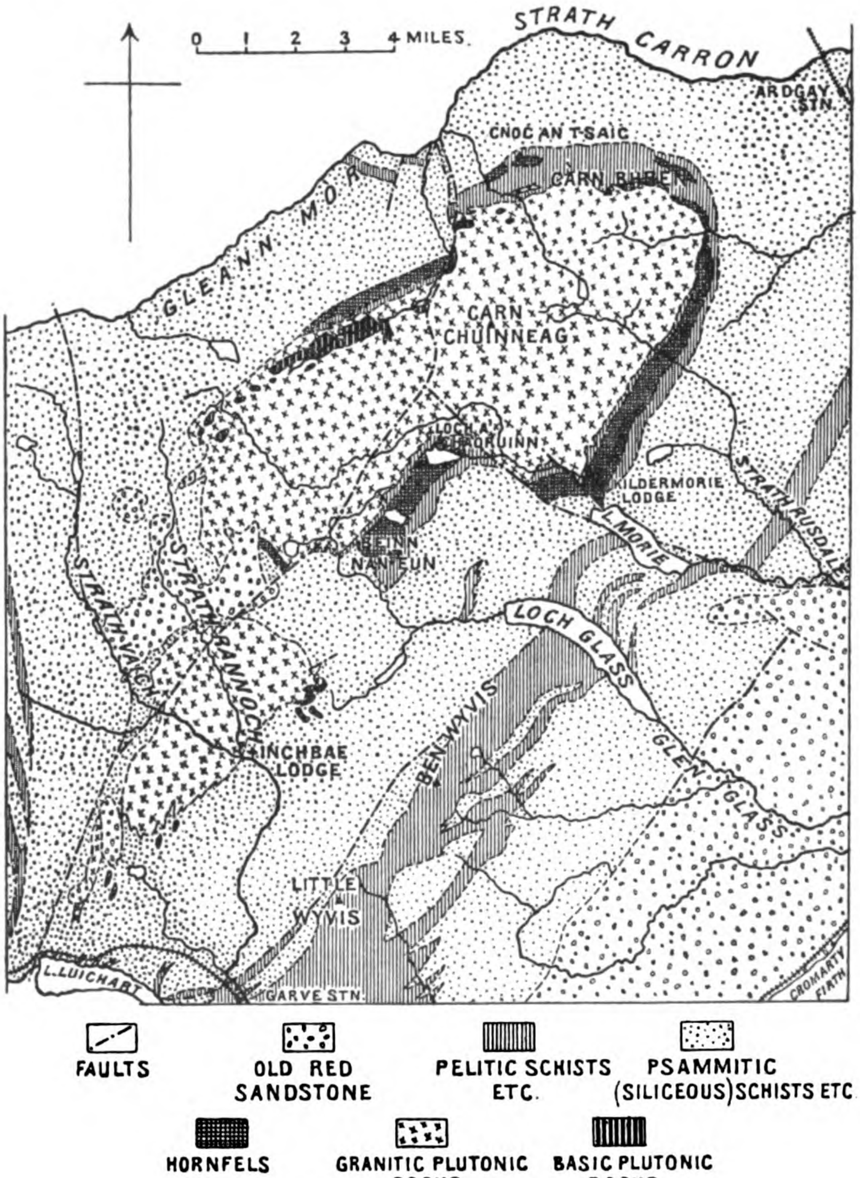


FIG. 23. Map of Càrn Chuinneag Augen Gneiss and pre-Moine Hornfels, Ross-shire. (*After C. B. Crampton and C. T. Clough in 'Geology of Ben Wyvis, Càrn Chuinneag, Inchbae', Plate* XII.)

miles in breadth. The Càrn Chuinneag plutonic complex, which is regarded as a laccolite, occupying the centre of a synclinal fold, is surrounded, except along its south and south-west boundary, by pelitic schist and hornfels (Fig. 23).

The greater part of these plutonic masses consists of augen gneiss, which was originally a porphyritic granite. In places, the large phenocrysts of orthoclase with their original idiomorphic outlines are preserved, and the original grains are not granulitized. Veins of granite, which are not much deformed, pierce the surrounding belt of hornfels, and patches of altered sediment occur in the granite.

Near the north-west margin of the Càrn Chuinneag mass basic modifications appear, including gabbros (without olivine), augite-diorites, quartz-diorites, and more acid types corresponding to tonalites and hornblende-granites. These rocks are sometimes not foliated and still show their original structures, but, in general, they have been changed by movement after consolidation into amphibolites, hornblende-schists and hornblende-gneisses. These basic inclusions are surrounded and veined by granite, and represent an earlier phase of the igneous material. It is suggested that they may have 'originated by the differentiation of an acid magma in much the same way as the basic rocks of Garabal Hill, and of so many other intrusions of the Newer Granite Series in the Scottish Highlands and the Southern Uplands'.

Areas of ægirine-riebeckite-gneiss appear near the centre of the Càrn Chuinneag complex, and masses of magnetite and tin ore (cassiterite) near its north-west margin. The latter are associated with dark biotite-gneiss, containing large rounded garnets and much albite.

The prevalent foliation in the granitic gneisses is NNE., in harmony with the strike of the Moine schists in the surrounding country, though it varies considerably from point to point. Where the basic inclusions have a common foliation with that of the granite and have undergone extreme deformation, the striped rocks simulate the structures of some of the banded gneisses in the Lewisian areas in the west of Sutherland and Ross.

The remarkable contact-altered rocks in the aureole were first recognized by Peach as hornfelses due to the action of granite on sandy shales. The hornfels is a blue, splintery rock with well-marked banding, indicating the original bedding planes of the sediments. The petrographical characters of these rocks and their passage into mica-schists are thus described:

'The minerals of the banded hornfelses are quartz, felspar and brown mica. Very generally they contain garnet, and sillimanite also is common as small prisms densely clustered. Pseudomorphs of andalusite are found only along certain bands, sometimes in the form of typical chiastolite with the black, cross-shaped markings, sometimes in large eumorphic prisms; but the mineral is always replaced by white mica and kyanite. Pseudomorphs after cordierite have been seen in one or two rocks, and there are also compact pyroxene-hornfelses derived from the marl-bands (calcareous shales) that give rise to the zoisite-hornblende-granulites under other conditions. The fine biotite-hornfels is often 'spotted' with small spots, exactly in the same manner as a spotted slate from the aureole of a Cornish granite. . . .

'The pelitic outcrop (in Loch a' Chaoruinn district), which originally must have been a single mass of shale or sandy shale, is now at some points an unsheared hornfels, while at others it has been converted into a garnetiferous mica-schist, with folds and foliation striking at right angles to the bedding in the hornfels.

'As we proceed outward from their centres, the masses of hornfels in other areas also can usually be traced passing into mica-schist, whether we move towards the granite or away from it. There are many intermediate stages between typical hornfels and typical mica-schist, one of the best marked being a fine greyish rock full of small micas, white and black. This may be called the stippled schist, and often forms a belt next the granite. It has more mica than the hornfels, especially muscovite, which has developed at the expense of felspar. The garnets of the hornfels persist, but the sillimanite and andalusite disappear. . . .

'The stippled schists are fissile as their micas have a parallel orientation that is lacking in the hornfels. It is a new structure, namely foliation. The direction of orientation often crosses the bedding, and, as the foliation develops, the sedimentary banding becomes less evident, though still persisting. The rocks are being sheared and interstitial movement is taking place; the dragging out of the andalusite proves this, and also the deformation of the quartz pebbles. In the other schists, which are more coarsely crystallized than the stippled schists, the mica plates get longer and larger; felspar vanishes almost completely, though sometimes a little albite makes its appearance. The ultimate product is a mica-schist with each plate of mica a hundred to a thousand times larger than those of the hornfels. We note the operation of three processes closely connected—(1) interstitial movement, (2) recrystallisation with orientation of the micas perpendicular to the directions of stress or along the planes of movement, (3) continued growth in size of the characteristic minerals of the schist. Here again chemical analyses have proved that the coarse mica-schist was originally the same rock as the fine blue splintery hornfels. . . .

'After the movements that produced the main foliation of the district had come to an end, and the rocks were for the most part in the same state as they are at present, a group of basic dykes (olivine-dolerites) were injected along a system of fissures that have mainly a NNW. trend. Thereafter movements again set in (posthumous movements), but on a lesser scale and more local in their distribution. They folded the previous foliation in the gneisses and schists, and their action appears in a concentrated form along certain crush-zones or belts of secondary shearing, which are narrow strips running in various directions, but often nearly at right angles to the strike of the general folding in the Moine rocks. . . .

'We believe that the granite gneiss and its aureole furnish us with an undoubted example of pure dynamic metamorphism. All the rocks involved—igneous, sedimentary, and the contact-altered hornfelses—were free from foliation when the movements began, and when the movements came to an end they were, in varying degrees of perfection, schists and gneisses as we find them now. This implies a similar history for the whole Moine system of the North of Scotland. The age of these rocks and the period or periods of movement that produced the foliation are not satisfactorily established, but that the movements occasioned the metamorphism is sufficiently clear.'[1]

The older acid igneous intrusions occur occasionally in the Moine area. Several examples have been observed of foliated granite and foliated pegmatite appearing as thin sills in the Moine gneisses, on the moor between Dochfour Hill and Lentran south of Beauly Firth. The foliation is more or less parallel with that in the adjacent schists. In some specimens the original structures are not destroyed though the effects of deformation are obvious under the microscope (Geol. Surv. Sheet 83).

In the north and east of Sutherland (Geol. Surv. Sheet 115), the members of the Moine Series are penetrated by granites more or less foliated and exhibit '*lit par lit*' injection of granitic material into the schists on an extensive scale. No contact-metamorphism resembling the hornfelsed rocks round the Càrn Chuinneag granite mass was observed.[2] The veins, bands and folia of granitic material showed no chilled margins with the intervening layers of Moine schist. Teall[3] noted the interlocking of the minerals between the granitic constituents and the granulitic rocks of that region, and pointed out that this would be the case if the crystallization of both rocks had been practically simultaneous. It was then inferred that the granitic injections were closely associated with the metamorphic processes, but it appeared probable that they found the schists already crystalline.

A remarkable development of similar phenomena has been described by Dr. H. H. Read in connexion with the mass of granodiorite at Rogart, Sutherlandshire.[4]

[1] See also 'Geology of Ben Wyvis, Càrn Chuinneag, Inchbae and the Surrounding Country', *Mem. Geol. Surv.* (1912), where a detailed description of the rocks of this important area is given.

[2] J. Horne and E. Greenly 'On Foliated Granites and their Relations to the Crystalline Schists in Eastern Sutherland', *Quart. Jour. Geol. Soc.*, vol. lii (1896), p. 633.

[3] 'Annual Report of the Geological Survey for 1894' (1895), p. 282.

[4] 'Geology of the Country around Golspie, Sutherlandshire', *Mem. Geol. Surv.* (1925), pp. 21–40.

FAULTS

The Moine area is traversed by several powerful lines of dislocation to some of which reference may be briefly made. They belong mainly to two systems, one trending north-east and south-west and the other north-west and south-east.

The Great Glen fault is the most striking example of the former, as it constitutes a great structural feature across Scotland which is still occasionally affected by earthquake movements. Its minimum displacement in the Ness valley, where the Middle Old Red Sandstone is thrown down on the south-east side against the Moine schists, is 6,000 feet. On the shore of the Black Isle north-east of Inverness, Jurassic strata are dropped by the same fault towards the south-east against a prominent sea cliff of Middle Old Red Sandstone. It has been observed that the crystalline schists on the north-west side of this fracture in the Loch Linnhe region show a higher grade of metamorphism than those on the south-east side, but this feature does not apply to the members of the Moine Series on either side of the Great Glen in the valley of the Ness.

Another example of the same system is the Strathconon fault which has been traced from the head of Loch Luichart south-westwards along part of the valley of the Meig and along Gleann Chorainn to Loch Monar and the heights beyond that loch (Geol. Surv. Sheet 82). It is believed to be a continuation of the fracture that passes out to sea at Loch Hourn, five miles south of Glenelg (Geol. Surv. Sheet 71), though all the intervening ground has not been mapped by the Geological Survey. It is regarded as a great wrench-fault by which the strata on the north-west side of the fracture have moved in a south-west direction and those on the south-east side towards the north-east. The lateral movement is indicated by the torsion of the strata towards the fault and by the horizontal striae on the slickensided surfaces in the lines of crush. The belt of crushed and haematite-stained rock along the fracture in the Glen Orrin district is more than a mile in breadth. From the head of Loch Luichart it runs north-eastwards across the granite masses of Inchbae and Càrn Chuinneag to the valley of the Carron west of the Dornoch Firth. A branch of this dislocation has been followed up Strath Vaich NNW. of Inchbae (Geol. Surv. Sheet 93). If we may assume that the Strathconon fault is a continuation of that passing out to sea at Loch Hourn, then its course must be over sixty miles.

The Strath Glass fault (Geol. Surv. Sheet 83) and the two faults in the Findhorn valley throwing down Middle Old Red Sandstone rocks in the midst of the Moine Series also run parallel with the Great Glen fracture.

The Loch Maree fault, which belongs to the north-west and south-east system, has been traced up Glen Docherty and thence to Scardroy and Loch Beannacharain where it is apparently cut off by the Strathconon fracture (Geol. Surv. Sheet 82).

Dr. Peach's Hypothesis that the Moine Schists are Metamorphosed Representatives of the Torridon Sandstone

The evidence set forth in this chapter is thus interpreted by Dr. Peach:

i. The inliers of gneiss in the Moine area in the counties of Sutherland, Ross, and Inverness are grouped with the Lewisian Gneiss on the western seaboard of Sutherland and Ross, and are therefore of pre-Torridonian age. They formed the floor on which the Moine sediments were laid down.

ii. The members of the Moine Series are a great sedimentary system of crystalline schists, resting unconformably on the inliers of Lewisian Gneiss with a conglomeratic base at certain localities.

iii. The occurrence of Torridonian strata in the post-Cambrian thrust masses, between Ben More Assynt, Sutherlandshire, and the Point of Sleat in Skye, proves that the Torridon Sandstone originally extended eastwards beyond its present limits.

iv. The displaced Torridonian strata west of the Moine Thrust were more or less deformed by the post-Cambrian movements, and mark initial and intermediate stages in the passage of Torridonian sediments into Moine schists. The difference in the grade of metamorphism on either side of the Moine thrust-plane in the Kishorn region, Ross-shire, is one of degree and not of kind.

v. The groups of the Moine Series established by the Geological Survey in Ross-shire are correlated with the recognized groups of Torridon Sandstone as shown below in descending order.

Torridon Sandstone		*Moine Series*
3. Aultbea Group,	correlated with	4. Upper Pelitic Group.
2. Applecross ,,	,, ,,	3. Upper Siliceous Group.
1. Diabaig ,,	,, ,,	2. Lower Pelitic Group. 1. Lower Siliceous Group.

vi. Owing to the uneven platform on which the Torridon Sandstone was deposited, the lowest Torridonian strata are overlapped by higher members of the formation. Similar evidence of overlap appears in the Moine area where higher zones of the Moine Series transgress lower zones, and rest directly on some of the inliers of Lewisian Gneiss.

vii. The granitic masses of Inchbae and Càrn Chuinneag, Ross-shire, which were injected into the Moine sediments before their regional metamorphism, belong to the same period of intrusion as the alkaline igneous rocks traversing the Cambrian strata in Assynt.

viii. The clean-cut thrust-planes, the deformation of the Torridon Sandstone, the regional metamorphism of the Moine Series, and the foliation of the laccolitic igneous masses of Inchbae and Càrn Chuinneag, were produced by the same set of movements in post-Cambrian time.

Peach's interpretation of the evidence is a comprehensive solution of the problems relating to the origin of the Moine schists, but, in view of conflicting evidence given below, his inference that the Moine schists are altered representatives of the Torridon Sandstone cannot be regarded as proved.[1]

i. For a distance of thirty miles from Loch Eireboll on the north coast of Sutherland to Loch Glencoul, no Torridonian strata occur in any of the displaced masses west of the Moine Thrust, because along that line in the undisturbed area immediately to the west, the Cambrian quartzites rest unconformably on the Lewisian Gneiss. The rocks in these thrust masses consist of Lewisian Gneiss and Cambrian strata. But, on the east side of the Moine Thrust, the characteristic types of the Moine Series occur on the Moine moor and have been traced southwards to the hills east of the head of Loch Glencoul, *as if the Torridon Sandstone were not an essential factor in their formation.*

ii. The striking feature of the Torridon Sandstone in the North-West Highlands is the great lateral variation in the character of the strata between the north coast of Sutherland and the Point of Sleat in Skye. The lowest subdivision (Diabaig Group), as already indicated, is not represented in the Cape Wrath district. In Ross-shire its thickness varies from 250 to 700 feet, and in Skye it amounts to over 7,000 feet. There is no corresponding variation in the lithological character of the Moine schists along this line. The various types of the Moine Series are remarkably uniform and persistent.

iii. At the base of the Torridon Sandstone between Cape Wrath and the Point of Sleat in Skye, local conglomerates appear at intervals along the line. In the northern tracts the pebbles are well-rounded, but in parts of Ross-shire coarse breccias or conglomerates, containing fragments of the underlying rocks, also occur. In South Ross-shire and in Skye, epidotic grits and conglomerates form the typical

[1] In 1910 Clough stated 'that the evidence at present available does not warrant the conclusion that the Moine rocks represent Torridonian rocks'. See 'Geology of Glenelg, Lochalsh and South-East Part of Skye', *Mem. Geol. Surv.* (1910), p. 46.

basal beds. The detailed mapping by the Geological Survey has proved that the occurrence of a conglomerate at the base of the Moine Series in contact with the inliers of Lewisian Gneiss is exceptional. Rocks resembling the basal epidotic grits and conglomerates of the Torridonian are extremely rare at the base of the Moine Series.

Clough, as previously stated (p. 171), called attention to the absence of epidotic conglomerates at the base of the Tarskavaig-Moine schists in Skye. He accounted for their absence, and for certain other lithological differences, on the supposition that these schists had been pushed from an area in which the conditions of deposition differed from those indicated by known Torridonian groups elsewhere.

iv. The siliceous granulites of the Moine Series seem to be more siliceous than the grits of the Diabaig and Applecross groups of the Torridon Sandstone.

An alternative hypothesis, adopted by Dr. Horne, regards the Moine Series as consisting mainly of sedimentary schists of pre-Torridonian age, modified by post-Cambrian movements, which developed, along the outcrop of the Moine Thrust, a complex of mylonites, green schists, phyllites, lenticles of Cambrian quartzite, of schistose Torridon Sandstone, sills of foliated igneous material resembling types intrusive in the Cambrian strata in Assynt, and deformed Moine schists, with common planes of schistosity determined by these movements. These pre-Torridonian sedimentary schists, as previously stated, formed part of the land barrier separating the Cambrian sea in the North-West Highlands from the sea in which the fossiliferous Highland Border Rocks were deposited.

VI[1]

ISLAY AND COLONSAY

In giving the territorial name Dalradian to the congeries of schistose rocks of the Central and Southern Highlands, Sir A. Geikie was well aware that it could only be a temporary one, that its components would, sooner or later, be classified under the respective formations to which they really belong.

Already the rocks of Colonsay and Western Islay have been wrested from this 'waste basket' and shown to belong to the Lewisian and Torridonian divisions. They are much affected by movement but not to such an extent as to preclude their recognition. Further, a narrow strip (the Highland Border Rocks), seen at intervals along the extreme Highland Border, has been shown by fossil evidence to be of Upper Cambrian and Ordovician age.

Islay and Colonsay form the western extension of a wide area, which stretches for sixty miles to the north-east and is at least twenty miles across, where nearly all the older rocks, both sedimentary and igneous, are in so low a state of metamorphism that they cannot be truly considered as crystalline schists, although they show the effects of movement in a marked degree in places. The 'Great Glen Fault' forms the northern boundary of this region. Immediately to the north of this line the rocks show a high grade of metamorphism which they had acquired prior to their invasion by granites, of which that of the Ross of Mull is the most westerly mass. These intrusions have superimposed their contact metamorphism upon that of the prior regional one, so that the contrast between the rocks north and south of the line is most striking. There is little or no doubt that, owing to the profound downthrow of the fault and to subsequent denudation, two sets of rocks are now exposed at the surface side by side which received their metamorphism under highly contrasted conditions of load.

The contention that the Moine Schists north of the Great Glen Fault are only the reappearance of the Torridonian rocks west of the Moine Thrust obtains additional support from the study of the rocks entering into this region of low metamorphism south of the Great Glen Fault, which extends roughly from Fort William to Colonsay. In the Moine Schists to the north of the line there is everywhere evidence of interstitial movement as well as of molecular and chemical

[1] See Appendix, p. 225.

reconstruction; whereas, to the south of it, there is almost everywhere evidence of the breaking down of former structures by cleavage, strain-slip, and major and minor thrust-planes, the rocks having behaved as more or less brittle bodies. Away from this area to the north-east and east there is a gradual rise in the grade of metamorphism which can be followed in individual bands of rock that extend from one area to the other.

Notwithstanding the low grade of metamorphism of the rocks in Islay and Colonsay it is almost certain that the outcrop of the Moine thrust-plane is under the sea still farther to the west and that these rocks lie above it and to the east of it. There is a certain body of evidence in support of the contention that the Moine thrust-plane traverses the Sound of Iona;[1] but, if so, the effect of the Great Glen Fault would be to throw the outcrop of so lowly inclined a plane much farther to the westwards. Bailey[2] suggests that the Loch Skerrols thrust-plane in Islay is the Moine thrust-plane, but if so, when we get away from the immediate vicinity of it, the rocks on each side are in the same low grade of metamorphism, in fact the rocks of the Rhinns are much more altered than those occurring on the shores of the Sound of Islay.

From what has been stated it is plain that this wide area lies well to the east of the outcrop of the Moine thrust-plane and that, owing to the downthrow of the Great Glen Fault, we have an area preserved to us in which is shown what was the condition of the rocks in the more superficial zones which overlay the highly altered rocks now exposed on the north side of the Great Glen.

[1] C. T. Clough in 'The Geology of Colonsay and Oronsay with Part of the Ross of Mull', *Mem. Geol. Surv.* (1911), p. 77. In regard to the Torridonian of Iona, T. J. Jehu ('The Archaean and Torridonian Formations and the Later Intrusive Igneous Rocks of Iona', *Trans. Roy. Soc. Edin.*, vol. liii (1922), p. 166) mentions that Sir Archibald Geikie, in *Nature*, vol. xl (1889), pp. 322, 323, at one time looked on the series of rocks on the east side of Iona as being at the base of the 'younger schists' of the Highlands named by him Dalradian, but that later, in his Geological Map (10 miles to 1 inch scale) he published them as doubtfully Torridonian. A. Macconochie, while storm-stayed on the island, collected a number of specimens, now exhibited in the Survey Collection in the Royal Scottish Museum; among these are basement conglomerate (made up of old gneiss and pegmatite fragments), arkoses, epidotic grits, and dark slightly cleaved shales. None of them is much deformed but they are slightly hornfelsed and baked by proximity to igneous rocks. It was this discovery which led Geikie to modify his views. Jehu, after his careful examination of the whole island, compares these eastern rocks with Clough's Loch na Dal Group of the Torridonian of Skye. Among the boulders and pebbles of the basement grits and conglomerates he notes 'red soda granite, gneiss, quartz-syenite (resembling nordmarkite), red pegmatite (similar to the latest pegmatites in the Archaean), aplite, vein quartz, and jasper'.

[2] 'The Islay Anticline (Inner Hebrides)', *Quart. Jour. Geol. Soc.*, vol. lxxii (1917, for 1916), p. 139.

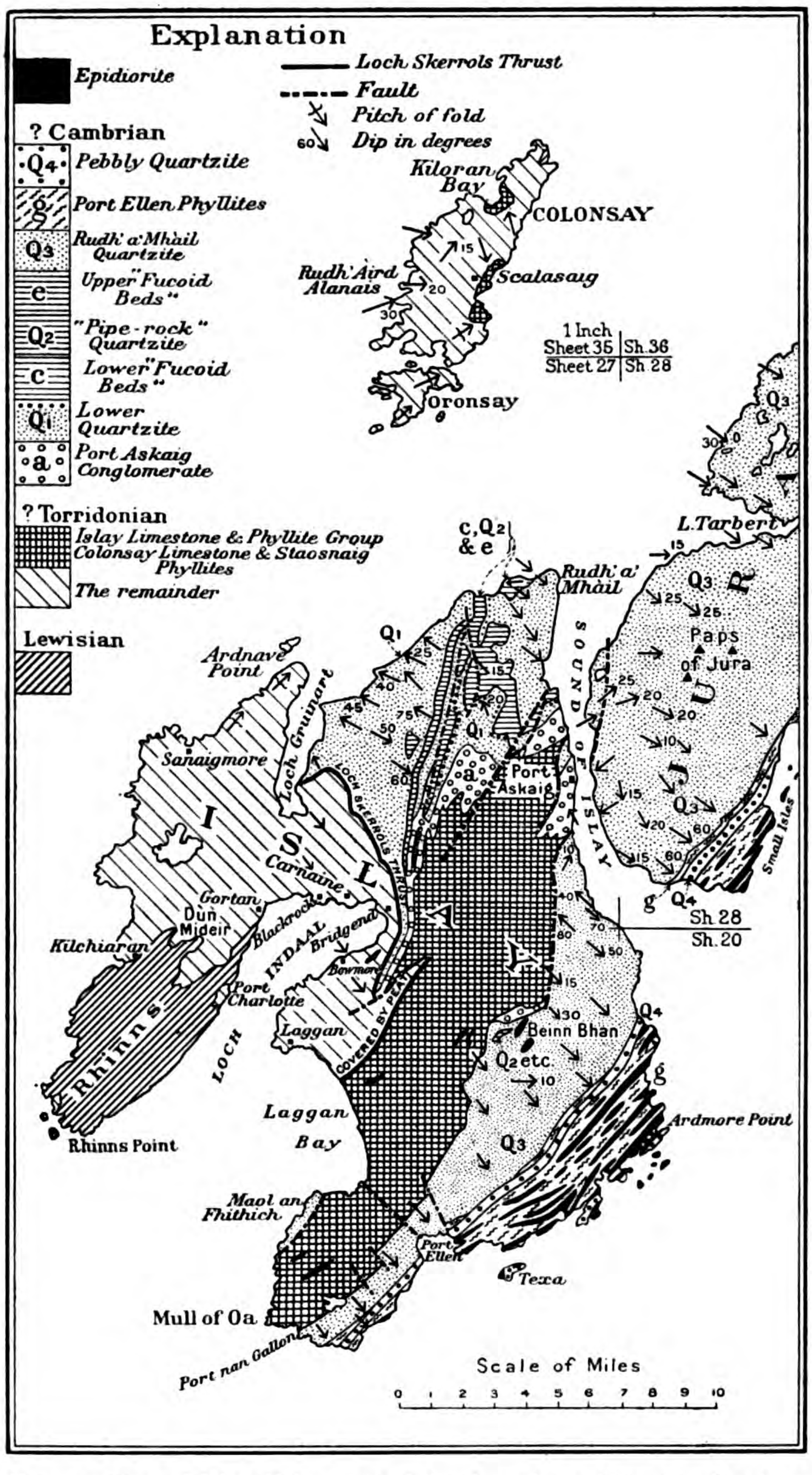


FIG. 24. Map of Islay, Colonsay, and Southern Jura. (*Based on Sheets* 19, 20, 27, 28, 35, 36, *Geol. Surv. One-inch Map Scot. and E. B. Bailey, 'Quart. Journ. Geol. Soc.', vol.* lxxii, *Pl.* XII.)

The rocks of Islay and Colonsay are perhaps the least altered in the whole of the above-mentioned area of low-grade metamorphism, and it is there that two at least of the great divisions occur that have been recognized with some considerable degree of certainty, viz. (1) Lewisian, and (2) Torridonian; while there is a considerable body of evidence in favour of another group, including the Port Askaig Conglomerate, the Quartzites and the so-called Fucoid Beds, being the equivalents of part of the Cambrian rocks of the North-West Highlands, but with a change of facies. Two sections across Islay are given in Pl. XVIII.

Lewisian

The description of the Lewisian rocks of the Rhinns of Islay by Wilkinson and Teall leaves no room for doubt that they are dealing with part of the old Lewisian floor upon which the Torridonian rocks were laid down. The manner in which the basic dykes cut the more felspathic gneisses of the 'fundamental complex' of 'acid and basic orthogneisses of probable igneous origin',[1] and the presence of 'the pale green augite similar to that occurring in the pyroxene-gneisses of the North of Scotland',[2] not infrequently in association with hypersthene in the larger basic masses, are both very significant. Further the occurrence of coarse red pegmatites (presumably oligoclase rocks) which cut most or all of the other rocks of the complex adds still further evidence in support of that conclusion. Some paragneisses of sedimentary origin, occurring near Portnahaven and doubtfully attributed in the Geological Survey Memoir to the overlying Torridonian, though in a more advanced stage of metamorphism than elsewhere in the island, may actually be a representative of the Glenelg and Loch Maree schists of pre-Torridonian age.

The nature of the decomposition of the rocks of the old Lewisian floor upon which the Torridonian rocks of Islay rest is identical with that which occurs in the North-West Highlands and in Iona.

Torridonian

The description of the Torridonian rocks of Islay as given in the Geological Survey Memoir is sufficiently convincing to show that the rocks west of the Loch Skerrols thrust-plane represent parts of the Diabaig, Applecross, and probably the Cailleach Head (Aultbea) rocks of Skye and West Ross-shire. The evidence that the Carnaine Beds may represent the Aultbea Group is not quite on the same footing as the rest, although the general assemblage of rocks is much alike

[1] J. J. H. Teall in 'The Geology of Islay', *Mem. Geol. Surv.* (1907), p. 15.
[2] Ibid., p. 17.

in both localities; and, certainly, the Islay beds are not a bit more altered than are the Upper Torridonian rocks associated with Cambrian Quartzite beneath the Kishorn thrust-plane west of Cnoc Damh, in the Coulin Forest of Ross-shire.

The study of the Colonsay memoir (Sheet 35) shows that the island is mainly built of Torridonian rocks. The succession of the rocks has, however, been worked out in much greater detail than was attempted in Islay, notwithstanding which there are certain outstanding points that allow of a rude correlation between the rocks of the two islands and also with the succession displayed in the North-West Highlands. Just as was the case in the North-West Highlands, there is great variability in the rocks of the zones established by the Geological Survey, even in such a small area as that of Colonsay.

Wilkinson in connexion with his work in Islay surveyed the south end of Colonsay and the island of Oronsay, which is attached to Colonsay at low tide. When I inspected Mr. Wilkinson's work we were of opinion that the rocks of Oronsay were the same in character as those of Sanaig Point and Ardnave on the north-west coast of Rhinns of Islay, and Wright and Bailey agreed with this conclusion after visiting the Rhinns of Islay. On the other hand, there is reason to suppose that the Ardnave and Sanaig Beds may represent more than the Oronsay Group of the Colonsay sequence. Up to the top of the Kilchattan Phyllites the succession in Colonsay has a great resemblance to the Diabaig Group of the Sleat district of Skye, the Kilchattan Phyllites of the former being probably the Kinloch Beds of the latter. The succeeding Millbuie Group would then represent part of the great arkose or Applecross Group with which the Bowmore Grits of Islay are correlated. The Kiloran Flags of Colonsay are evidently the Carnaine and Dry Bridge flaggy group of Islay, the highest rocks seen there west of the Loch Skerrols thrust-plane.

Part of the Kiloran Flags, the Colonsay Limestone Group, and the Staosnaig Phyllites are in all probability the same rocks as are brought forward, along with the ?Cambrian quartzites (p. 210), upon the Loch Skerrols thrust-plane in Islay; for it is to be remembered that, if allowance has to be made for a considerable amount of variation in such a short space as between Scalasaig and Kiloran Bay in Colonsay, there may have been a still greater variation over the much wider space that separates Central Islay from North Colonsay. It must also be taken into account that, owing to some amount of unconformability between the quartzite series and the underlying Islay Limestone Group, the Port Askaig Conglomerate of the ?Cambrian succession is found to transgress across the boundary between the limestone and its slate and phyllite associates. It has not been definitely shown

TORRIDONIAN CORRELATIONS

WEST SUTHERLAND, ROSS AND SKYE	ISLAY	ORONSAY AND COLONSAY
Aultbea Group	Islay Limestone Group, including limestone, black slates and phyllites and occasional quartzite bands.	8. Staosnaig Phyllites. 7. Colonsay Limestone Group.
	Loch Skerrols Thrust	*No Thrust*
	Carnaine Beds, fine arkoses, flags, and dark shales.	6. Kiloran Flag Group.
Applecross Group	Bowmore Grits and Arkoses, with Black-rock pebble bed.	5. Millbuie Group.
Diabaig Group	Ardnave and Sanaig Beds, including grits, flags, and slates with thin limestones.	4. Kilchattan Group. 3. Machrins Group. 2. Dungallan Group. 1. Oronsay Group.
	Kilchiaran Slates, Basement Conglomerates and Epidotic Grits of Rhinns of Islay.	Probably unrepresented.
Strong	*unconformability*	*with overlap*
Lewisian	Lewisian	Lewisian

whether the dark schist in Islay is above or below the limestone. It may be that it both underlies and overlies it just as the black slate occurs both above and below the upper limestone in the Kiloran Bay section of the Colonsay Limestone Group.[1] The Staosnaig Black Slates or Phyllites, overlying this upper and purer limestone, in all probability represent some of the black slates that have been extensively quarried in Islay between Bridgend and Ballygrant.

In Islay, the Loch Skerrols thrust-plane [2] has weakened the value

[1] W. B. Wright and E. B. Bailey in 'The Geology of Colonsay and Oronsay . . .', *Mem. Geol. Surv.* (1911), p. 26.

[2] J. F. N. Green ('The Structure of the Bowmore-Portaskaig District of Islay', *Quart. Jour. Geol. Soc.*, vol. lxxx (1924), p. 87) endeavours to prove the non-existence of the Loch Skerrols thrust-plane. I am somewhat in the same position as the woman who said to the person who tried to convince her of the non-existence of the Devil: 'I wish to God it were true'. Its outcrop is seen on the shores of Loch Gruinart where the flaser quartzite is seen above and the equally drawn-out Bowmore grits beneath. It is also seen between that section and Loch Skerrols. At the latter place the quartzites are intensely drawn out and folded, while the Bowmore arkoses a short distance off are very much less affected.

of the evidence, but fortunately in Colonsay no such structure has been discovered as intervening between the rocks correlated with the Ardnave Beds in Islay and the Colonsay Limestone and Staosnaig Phyllites, which may well represent the black slates and limestone of the Islay Limestone Group.

There is still another connecting link in the chain of evidence which supports this correlation of the Colonsay Limestone Group with that of Central Islay. Certain breccias accompany syenite intrusions that have penetrated the Colonsay Limestone and Staosnaig Phyllite Groups in the Kiloran Bay sections, and are made up of blocks of the local Torridonian rocks with a large percentage of quartzite blocks. These blocks are considered by the authors of the Colonsay Memoir to have fallen from above into the fissure or pipe followed by the uprising syenite.[1] It looks as if the Kiloran Bay rocks had been immediately overlain by quartzites with near their base a comparatively uncompacted sandy boulder-bed (?Port Askaig Conglomerate) containing quartzite boulders which could have readily supplied such materials. (*Note.*—It would be interesting to search the quartzite for worm-pipes. The breccias should also be searched for nordmarkite boulders.) On page 35 of the Colonsay Memoir the authors state of the Kiloran Breccia:

'At its extreme outer edge, where it comes in contact with the phyllites, the breccia is composed of angular fragments of the latter interlocked with one another in the close-fitting manner of Pl. V [of Colonsay Memoir]. A few feet from the margin, boulders and great angular blocks of quartzite foreign to the island begin to make their appearance and soon form a large part of the mass. Blocks of whitish limestone, probably the adjoining Torridonian limestone in a baked condition, and fragments of lamprophyre also occur. Some of the quartzite boulders even when as much as 2 ft. in diameter are so remarkably well rounded as to be suggestive of water action [probably rounded boulders out of the Port Askaig Conglomerate, B.N.P.]. The quartzite, of which they and the much larger masses consist, is frequently pebbly and, as far as can be seen, indistinguishable from that which in Islay is thrust forward on the Torridonian rocks. It is therefore similar also to the quartzite occurring as small pebbles at two horizons, in conglomeratic beds of the Torridonian sequence of Colonsay.'

[1] W. B. Wright and E. B. Bailey in 'The Geology of Colonsay and Oronsay . . .', *Mem. Geol. Surv.* (1911), pp. 34–6, Figs. 4, 5, Pls. IV, V. For similar occurrences of breccia in Scotland cf. B. N. Peach in 'The Geological Structure of the North-West Highlands of Scotland', *Mem. Geol. Surv.* (1907), pp. 435, 436, Fig. 19; B. N. Peach and J. Horne, 'The Old Red Sandstone Volcanic Rocks of Shetland', *Trans. Roy. Soc. Edin.*, vol. xxxii (1884), pp. 377, 378, Fig. 14; C. T. Clough in 'The Geology of Mid Argyll', *Mem. Geol. Surv.* (1905), p. 93; H. B. Maufe in 'The Geology of the Country near Oban and Dalmally', *Mem. Geol. Surv.* (1908), p. 80—in this last case Maufe interprets the breccia as a surface deposit.

The size of the rounded blocks, reaching up to two feet, and of the larger angular blocks mentioned precludes the possibility of their having been blasted out as pebbles from the underlying pebble beds. It appears more probable that, in Lower Old Red Sandstone times, the Quartzite Series of Islay still overlay this part of Colonsay and that the material fell into the pipes from above. The occurrence of lamprophyre fragments in the breccias is easily explained, for, in Islay and Colonsay, lamprophyre dykes and sheets, intruded into the Torridonian sediments and Lewisian gneiss alike, are folded and rendered *flaser* by the movements which brought about the Loch Skerrols thrust-plane long prior to the deposition of the Lower Old Red Sandstone.

In the North-West Highlands the unconformability between the accepted Cambrian and any older rocks is so great that the Basement Quartzite may rest successively upon all the subdivisions of the Torridonian and even encroach upon the underlying Lewisian Gneisses and Schists. The highest Torridonian beds observed are exposed on Cailleach Head lying between the mouths of Loch Broom in Wester Ross, where they consist of fine-grained flaggy arkoses and sandstones, sandy dark carbonaceous flags and shales; some of the beds are calcareous but none could be called a limestone. Some of the dark beds, however, hold small phosphatic nodules which contain cells and fibres, thus indicating that organized structures enter into the rocks; and the dark, almost black, colour of some of the flags and shales is evidently derived from organic matter. It is therefore probable that the passage from arkoses to fine deposits, blackened by organic matter, may have been the prelude to the deposition of limestones which may have been denuded off the Torridonian prior to the deposition of the Basal Quartzite. May not the Islay and Colonsay Limestones fill in the gap?

Another point must be taken into consideration, viz. the Cambrian rocks of the North-West Highlands are exposed in the direction of strike along a comparatively narrow belt. Within this belt they show a remarkably even continuity down to very thin zones. In the North-West Highland Memoir of the Geological Survey this constancy of facies was attributed to their having probably been deposited parallel to the shore line of the Archaean continental area from which their sediments had been derived. It would be natural to suppose, however, that change of facies would take place more readily in a direction transverse to that of strike. Still another contingency might be looked for, viz. the Cambrian strata of the North-West Highlands were deposited on a subsiding area, as shown by the succession of beds from pebbly arkose-like quartzites through shales to limestones and dolomites practically free from terrigenous sediment. It is only natural therefore to expect lower and older sediments belonging to the Cambrian succession to the south-east of the narrow belt in which they are now exposed. The same reasoning would lead us to look south-eastwards for newer Torridonian rocks than those of Cailleach Head. If such were the case the unconformability between the two sets of beds would decrease in the same direction and it may be that in the Central and Southern Highlands we have found some of both the younger Torridonian and older Cambrian rocks that help to fill up the hiatus—the slight amount of unconformability between the Port Askaig Conglomerate and the Islay Limestone Group may thus be accounted for.

It is in view of the above considerations that I consider the Port Askaig Conglomerate to be the base of the Quartzite or Cambrian succession of rocks and that it is on the same general horizon as the conglomerate (boulder-bed) with nordmarkite pebbles occurring at the base of the quartzite of Schiehallion and probably that of Braemar. It is certainly the same as the boulder-bed of the Garvellachs or Isles of the Sea.

My reading of the Colonsay succession (p. 206) shows that Mr. Bailey's idea, that the Great Glen Fault passes east of Colonsay and down Loch Gruinart through Islay,[1] becomes nugatory, for the Bowmore grits occur on both sides of the supposed line of fault: north-west of the line in Colonsay (and also on the Rhinns) and south-east of the line at Black Rock and Bowmore.

? Cambrian Rocks of Islay

Before proceeding to the consideration of the rocks of probable Cambrian age in Islay, it is necessary to state that in my opinion the work of Bailey[2] has rendered no longer tenable the order of succession of the rocks of Islay as set out in the Islay Memoir in which I am deeply implicated and for which I am in great part responsible. In that memoir the Port Ellen Phyllites were correlated with those of the central belt and supposed to be, like the latter, unconformably overlain by the quartzite group. All the quartzites were supposed to be overlain by the 'Fucoid Beds' whereas the greater part of the Islay quartzites really overlies them.[3] At the time of Bailey's visit to the north coast west of the Rudh' a' Mhàil, the beach deposits, which

[1] 'The Islay Anticline (Inner Hebrides)', *Quart. Jour. Geol. Soc.*, vol. lxxii (1917 for 1916), Fig. 3, p. 138.
[2] Ibid., p. 149.
[3] In Islay the quartzite is really not one bed but a succession of sandy sediments alternating with finer grained sediments (shales often blackened with organic matter and limestones) denoting changes brought about by intermittent subsidence.

masked the structures at the foot of the cliffs bounding the Bagh an dà Dhoruis (Bay of the Cave of two Gates) during the former visits of the Geological Survey,[1] had been swept away by the waves, so leaving the junction of the 'Fucoid Beds' and quartzite bare. Thus a clear passage from the 'Fucoid Beds' up into the quartzite was exhibited and it was seen not to be a line of fault, as had been previously supposed. It is true that in the Margadale River section farther to the south a natural passage between the two sets of rocks was observed by Wilkinson and myself, but a wrong interpretation of the phenomena was adopted by us both, viz. that the rocks were inverted [2] and that the 'Fucoid Beds', to the west, were higher in the succession than the quartzite to the east.

As a natural corollary to Bailey's interpretation it follows that the quartzites west of Rudha Bholsa are the same as those of the Rudh' a' Mhàil which had arched as a compound anticlinal fold over the intermediate exposures of 'Fucoid Beds' brought forward on the Loch Skerrols thrust-plane. Bailey's discovery also carries with it the recognition of the quartzites to the south-east of Beinn Bhàn as being the same as those of Rudh' a' Mhàil and the superposition of the Port Ellen phyllites upon the quartzites.

ORDER OF SUCCESSION OF THE QUARTZITE GROUP (? CAMBRIAN) IN ISLAY

(*h*) Pebbly Quartzite (Q_4): highly pebbly with blocks of limestone, black and grey slate, and some felsitic fragments, one of granite observed. Port Ellen Distillery, Rudha nan Leacan and Ardmore in Islay; Texa Island; east coast of Jura and Scarba; and Ardnoe Point of Mainland, near Crinan.

Local Erosion

(*g*) Port Ellen Beds: black and grey slates and phyllites with some grits and limestones.

(*f*) Rudh' a' Mhàil Quartzite (Q_3): divisible into several zones in Jura and Scarba.

(*e*) Upper 'Fucoid Beds': sandy dolomitic beds with *Planolites* and bands of cream-coloured dolomite with *Stromatolites* (Kallowski).

(*d*) Pipe-Rock Quartzite (Q_2): about 100 ft. pure quartzite with three types of pipes '*Scolithus linearis*', viz. (1) 'Small pipes', (2) 'Common pipes', (3) 'Trumpet pipes', of the North-West Highland Cambrian quartzite.

(*c*) Lower 'Fucoid Beds': sandy dolomitic shales and flags often ripple-marked and sun-cracked and containing *Planolites*, the so-called 'Fucoids'.

(*b*) Lower or fine-grained Quartzite (Q_1): often flaggy and streaked with sandy pelitic material locally conglomeratic near its top with well-

[1] B. N. Peach in 'The Geology of Islay', *Mem. Geol. Surv.* (1907), p. 52.

[2] B. N. Peach, op. cit., p. 52.

rounded pebbles of nordmarkite and other rocks like those found in the underlying Port Askaig Conglomerate, but smaller.

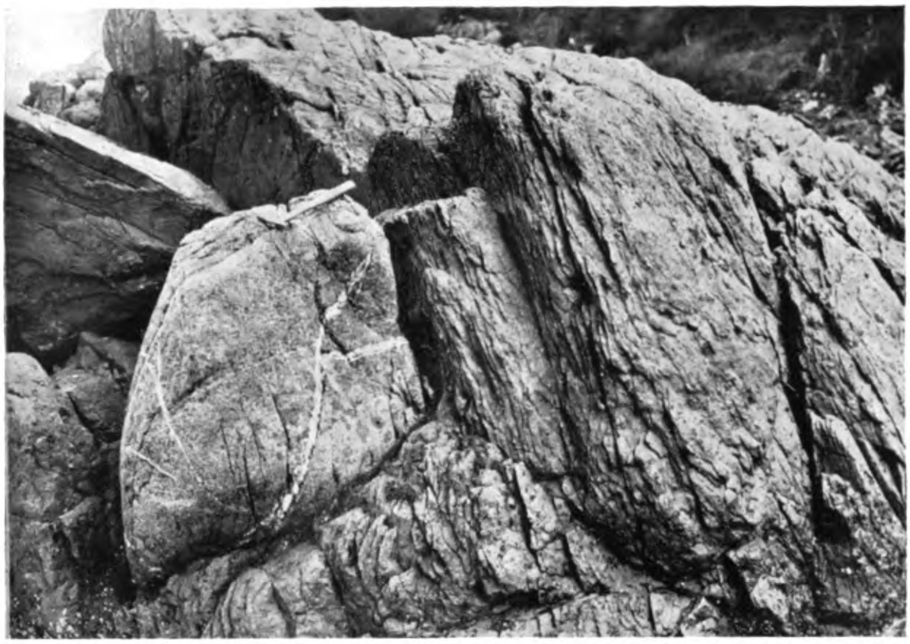
(*a*) Port Askaig Conglomerate: a peculiar tillite-like conglomerate with little or no stratification, the matrix largely made up of the debris of the underlying Islay Limestone Group and containing well-rounded boulders or pebbles of nordmarkite and other granitoid and gneissic rocks foreign to the region (Pl. XVI, 1). Bands of sandy dolomite are sometimes intercalated with the conglomerate both in Islay and Isles of the Sea.

The lettering Q_1, Q_2, &c., is employed to emphasize the recurrence of quartzite.

(*a*) *Port Askaig Conglomerate.*[1] (No. 1 of Islay Memoir, p. 42.) It is not necessary to describe this bed in detail, as it has been sufficiently dealt with in the Islay Memoir. The main point to discuss here is that there does not seem to be much evidence of unconformability between it and the Islay Limestone Group beyond what might have been brought about on an area undergoing depression with occasional uplifts from compression such as must have occurred during the deposition of the Ordovician rocks of the Southern Uplands. There is evidence that the limestone-phyllite assemblage of the Islay Limestone Group has undergone a certain amount of denudation and that fragments of its different members are found in the Port Askaig Conglomerate. We are therefore driven to the conclusion that some transporting agent, other than that which laid down the underlying finer sediments, must be held responsible for the large size of the blocks that occur in the Port Askaig Conglomerate, or Boulder Bed as it may more properly be called. The agency that suggests itself is that of floating ice. The presence of well-rounded boulders of alkali granites of unknown source favours this hypothesis rather than that of glacier ice, for the stones have all the appearance of having been

[1] J. F. N. Green ('The Structure of the Bowmore-Portaskaig District of Islay', *Quart. Jour. Geol. Soc.*, vol. lxxx (1924), p. 84) correlates the pebbly beds of the Bowmore Grits with the Port Askaig Conglomerate, and also with rocks west of Rudh' a' Mhàil, on account of the occurrence of alkali granites (nordmarkite) in all three. Now the fact is that pebbles of similar alkali granites occur in the Torridon conglomerates of Cape Wrath in North-West Scotland, in Iona (T. J. Jehu, 'The Archaean and Torridonian Formations and the Later Intrusive Rocks of Iona', *Trans. Roy. Soc. Edin.*, vol. liii (1922), p. 181), in the Aberfoyle grits (T. J. Jehu and R. Campbell, 'The Highland Border Rocks of the Aberfoyle District', *Trans. Roy. Soc. Edin.*, vol. lii (1917), p. 200), and in Ordovician grits at Carsphairn—at the last-named locality, according to Campbell, these pebbles are associated with felsitic pebbles identical in character with those described by Teall from Cape Wrath and other Torridonian exposures as like the Uriconian felsites of the Welsh Border. All this shows that the old 'Shield' existed to the north of our region throughout the period of deposition of the Torridonian and early Palaeozoic rocks. Of what value for correlation purposes is Green's identification of nordmarkite pebbles ?

PLATE XVI



1. Port Askaig Conglomerate or Boulder-bed with large boulder of veined nordmarkite, Port Askaig, Islay.

2. Scarba Boulder-bed, with lenticles of black slate in gritty matrix, Scarba shore, NNW. of Kilmory Lodge.

well rounded by wave action before transportation and of having been dropped sporadically among the calcareous muddy sand that forms the matrix of the Boulder Bed. The Port Askaig Conglomerate differs in this respect from the 'tillites' of the Finmark region of Scandinavia. Boulder-beds recur at several levels in the quartzite group of the islands and mainland of the Central and Southern Highlands of Scotland. In most cases they appear to be associated with local erosion of lately deposited materials, as if parts of the sinking areas were occasionally upheaved by compression so as to bring them into the zone of denudation.

(*b*) *The Lower Quartzite* (Q_1). (No. 2 of Islay Memoir.) The description of the Lower Quartzite given in the Islay Memoir is sufficient for my purpose. It is important to note that a boulder-bed occurs near its top and contains the nordmarkite and other alkali granite boulders similar to those found in the Port Askaig Boulder Bed, though not so large. The boulders are sporadically scattered, for they occur only in one of the sections where the rocks of the zone are exposed on the coast near Port Askaig. Outside of Islay, the same conglomerate is perhaps represented near Glengarrisdale in Jura, close to a piped quartzite which is listed as ?*d*, Q_2 in the following chapter. It recurs still farther to the east on the north face of Schiehallion, where the probable representative of the Port Askaig Boulder Bed outcrops farther down near the base of the mountain.

(*c*) *Lower 'Fucoid Beds'*. (No. 3 of Islay Memoir.) This is a group of greenish-grey sandy dolomitic flags and shales showing sun-cracks and ripple-marks and containing flattened worm-casts (*Planolites*). It is of much the same character as the lower part of the Fucoid-beds of the North-West Highlands.

(*d*) *Piped Quartzite* (Q_2). (No. 4 of Islay Memoir.) This division consists of about 100 feet of false-bedded quartzite, bluish in colour from the presence of blue quartz grains, and strongly recalls the rock of the 'Trumpet Pipe' Zone of the North-West Highlands. Some of the beds are prominently ripple-marked and vertically bored by three kinds of 'pipes' (*Scolithus linearis*) resembling the 'small pipes', the 'ordinary pipes', and the 'trumpet pipes' found in the Pipe-rock of the North-West Highlands. Pellicles of micaceous shale separating some of the quartzite bands are traversed along their bedding planes by sinuous worm-castings (*Planolites*) like those found in the Fucoid-beds of the North-West Highlands. Many of the surfaces of the beds are strongly rippled, and the 'small pipes', thin cylinders of sand, end upwards in conical depressions as they do in the North-West Highlands. 'Trumpet pipes' have also been recorded by Sir A. Geikie from Glengarrisdale in Jura (Fig. 25) in close proximity to where the conglomerate with nordmarkite boulders occurs in the quartzite. Sandy shales with plentiful *Planolites* occur close at hand. From the study of these rocks it is quite easy to show from the pipes and ripples whether the beds are in natural order or inverted.

(*e*) *The Upper 'Fucoid Beds'*. (No. 5 of Islay Memoir.) These consist chiefly of sandy shales with ripple-marks and worm-casts (*Planolites*) strongly resembling the Fucoid-beds of Sutherland and Ross, and massive beds of cream-coloured dolomite full of enigmatical structures which recall the variously named *Stromatolites* of Kallowsky, *Cryptozoon proliferum* of Hall, or *Gymnosolen* of Steinmann. The likeness of this group to that of the Fucoid-beds of the North-West Highlands in almost every detail is particularly striking. So much is this the case that a search was made on the shores of Bagh an dà Dhoruis, about one mile to the west of Rudh' a' Mhàil, for *Olenellus* remains in a succession of beds almost identical with that occurring in the typical Ross-shire locality on Meall a' Ghiubhais, but in vain. The peculiar bed which is used as a guide on Meall a' Ghiubhais, viz. a 'blue clay and sandy shale full of small vertical worm casts' (No. 7 of list given on page 414 of the North-West Highland Memoir) is perfectly imitated in the Islay section if not actually repeated, the difference in colour between the matrix and the cylindrical casts being equally pronounced in both cases. Unfortunately the search in Islay was fruitless as far as remains of *Olenellus* are concerned.

The structures referred to above as resembling the *Stromatolites* of Kallowsky are considered to be of the nature of a chemical deposit brought about by the action of organisms such as algae. These structures are very common in the Durness dolomites, but were not considered of sufficient importance to be described in the palaeontological chapter on the Cambrian rocks in the North-West Highland Memoir; but it is evidently to this structure in the Durness dolomites that 'Eozoon' is due where brought about by the contact metamorphism of the dolomites at Cnoc na Sròine by the post-Cambrian syenite and in the Strath district of Skye in Tertiary time by the granophyre and other plutonic masses.

I regret my overlooking the importance of these Stromatoliths when treating of the Durness Dolomites, because Walcott and other American geologists have since then considered them of zonal value as marking the Ozarkian (Cambro-Ordovician) horizon in America.

Returning to Islay, these Stromatolith structures are best shown in the outcrop of dolomite occurring round Loch Smigidail about three miles SSW. of Rudh' a' Mhàil. Wilkinson used to call the dolomite of this band the 'Elephant's tooth Limestone' on account of its Stromatolith structure.

(*f*) ***Rudh' a' Mhàil Quartzite*** (Q_3). Bailey has shown that this fine-grained quartzite really overlies the Upper 'Fucoid Beds' and that, owing to the anticlinal structure of the whole of the north of Islay, the quartzites of this zone are exposed along the coast-line from Rudha Bholsa to Loch Gruinart on the western limb of the fold. The arch, however, is highly compound and much more complex than shown in Bailey's section, and is much interrupted with faults or minor thrust-planes even where the underlying fucoid beds are not exposed by denudation. Before leaving the northern part of Islay it may be as well to state that, on account of constant repetition, there is no means of telling how thick the zone is and how much of it is represented in this part of the island.

Members of this quartzite form the larger part of the high ground to the south of the central valley stretching from the Sound of Islay to the Mull of Oa. A low-haded fault, with NE.–SW. trend and with downthrow to SE., crosses Islay Sound from Jura and enters Islay about 2¼ miles south of Port Askaig. Its course has been traced south-westward to Loch Allallaidh, about six miles east of Bowmore. Although it has not been followed beyond this point there is reason to believe that it extends through the whole length of the belt keeping near its north-west margin, so that an occasional interrupted fringe of some of the older zones (*a*, *b*, *c*, *d*, and *e*) appears at intervals to the north-west of the fault.

It is owing to this fault that it is only on the north flanks of Beinn Bhàn that the 'Fucoid Beds' (*c*) and the piped quartzite (*d*, Q_2) have been observed on the side of the central valley.

The top of this quartzite (Q_3) can only be seen along the south-eastern margin of this zone, where it is followed by a belt of grey and dark, almost black slates and phyllites stretching nearly continuously from Islay Sound to the sea two miles south-east of Mull of Oa.

(*g*) *Port Ellen Beds*. This is a group of grey phyllites and black slates and thin limestones with occasional bands of pebbly grit. In the Islay Memoir it was taken to be an upfold of the Islay Limestone Group of p. 207. It has been shown, however, by Bailey to overlie the Quartzite (*f*, Q_3), and to be in turn overlain by the succeeding group, the 'Pebbly Quartzite' (*h*, Q_4). This quartzite, according to Bailey, is in turn overlain by the main mass of the Port Ellen Phyllites, which he considers to be the highest beds in the Islay succession. I differ from him in this respect because the outcrop of pebbly quartzite which separates this strip of grey and black slates from the main mass of the Port Ellen phyllites is pebbly on both edges and contains fragments of the rocks which flank it on both sides. This strip of quartzite is therefore merely a downfold into the slates and phyllites. In the sequel it will be shown that this pebbly quartzite recurs to the south-east of the Port Ellen beds in Ardmore Point and Texa Island. It runs through nearly the whole length of Jura, Scarba, Lunga and the isles lying still farther to the north (Fig. 25), where it contains innumerable masses of the phyllites, limestones and grits that occur to the east of it.

(*h*) *Pebbly Quartzite* (Q_4). Where the slates of the former group (*g*) occur they are followed by a thin belt of pebbly quartzite with well-rounded pebbles of quartz sometimes as large as a pigeon's egg. The southern edge of the belt is often quite as conglomeratic as its northern one. Where the bed occurs near the Sound of Islay, a few small pebbles of a felsitic or granitoid rock also occur, showing that material was still being derived from the source that supplied the granitoid rocks to the Port Askaig Conglomerate. The most conspicuous feature of the belt is that the quartzite is often filled with the debris of the slates of zone (*g*) pointing to local erosion of the earlier pelitic bands. In places angular masses of the shales up to two feet in length crowd the rock, and often so much of the black shale has been incorporated that the quartzite becomes black. In places contemporaneous denudation has proceeded so far that the pebbly quartzite may be seen in conjunction with every member of the underlying group and in other places even with the preceding quartzite (*f*, Q_3), but in this case it is probable that a fault line intervenes. On the shore at Port Ellen Distillery black shale of (*g*) is found to the north of the outcrop of the strip of pebbly rock (Q_4) that flanks the quartzite hills made of (Q_3). There is evidence that the strip of pebbly quartzite here is the core of a synclinal fold. This evidence, I consider, is backed up by that obtained by Bailey to the northwards in Jura, where he has shown that this strip of pebbly quartzite (Q_4) traverses this island, with its breadth increasing as it is followed northwards and with all the characteristics of the belt as developed in Islay. Between Small Isles and Tarbert Bay in Jura (east coast opposite Loch Tarbert) the quartzite is, I think, repeated by numerous folds allowing belts of the underlying slate to alternate with the pebbly quartzite. The conglomerate in conjunction with this band of quartzite is described by Wilkinson as it occurs in cliff section a little to the north of Rudh' an Truiselaich near the north end of Jura (Fig. 25): 'In the cliff face, about 15 to 20 ft., pebbles and lenticular masses of derived rock occur embedded in a highly calcareous and cleaved matrix. There are pebbles of beautiful blue and violet and white quartz, limestone, felspars, grit and, I think, a few of a pale-coloured granite.'[1]

[1] S. B. Wilkinson in 'The Geology of Knapdale, Jura and North Kintyre', *Mem. Geol. Surv.* (1911), p. 103.

The Aird of Kinuachdrach in Jura (Fig. 25) is made up of these pebbly quartzites (*h*, Q_4). Both groups (*g*) and (*h*) extend northwards into Scarba and Lunga, but their relation to the quartzite (*f*, Q_3) is there obscured by a fault which runs through these islands and probably also extends southwards into Jura.

To return to Islay: the broad area occupied by the Port Ellen Phyllite group (*g*) is succeeded on the south by pebbly quartzites (*h*, Q_4) which enclose masses of earlier sediments. The outcrop of quartzite that forms Ardmore Point, the extreme east point of Islay, contains blocks of limestone like that which is intercalated with the phyllites a little to the north of the junction line. The quartzite also skirts the coast at intervals and extends into Texa Island.

In the sequel it will be contended that the Craignish Phyllites (Fig. 25) are the equivalents or rather the extension northwards of the Port Ellen Phyllites, and that the Ardnoe pebbly rocks of the Crinan district of the mainland are the equivalents of the pebbly quartzite (*h*, Q_4) of Islay.

Before leaving Islay it may be well to draw attention to the distribution of the epidiorite and hornblende-schist sills in the rocks east of Loch Indaal. A few sills of epidiorite are found in the Torridonian rocks between Bowmore and Bridgend. They also occur sporadically throughout the Islay Limestone Group underlying the Port Askaig Conglomerate in the central valley of the island. Several outcrops of epidiorite appear among the quartzites of group (*f*, Q_3) round about Beinn Bhàn, but these probably only represent a single sill repeated by folding and now isolated by denudation. As far as Islay is concerned, these sills are best developed in the Port Ellen Phyllites, but the large spread that epidiorite makes is in all probability the result of much repetition by folding, and of subsequent denudation. They also occur with the pebbly quartzite (*h*, Q_4) at Kildalton and on the island of Texa. It is plain that they were intruded prior to the folding and appear to be the underground expression of the volcanic zone which on the opposite shores of the mainland forms the Keills or Tayvallich Peninsula and almost immediately overlies the Pebbly Quartzite zone. They evidently invaded the Port Ellen Phyllites when these were not covered by a very heavy load of overlying strata.

VII[1]

THE NORTH END OF JURA, SCARBA, LUNGA, EILEAN MÒR, GARVELLACHS

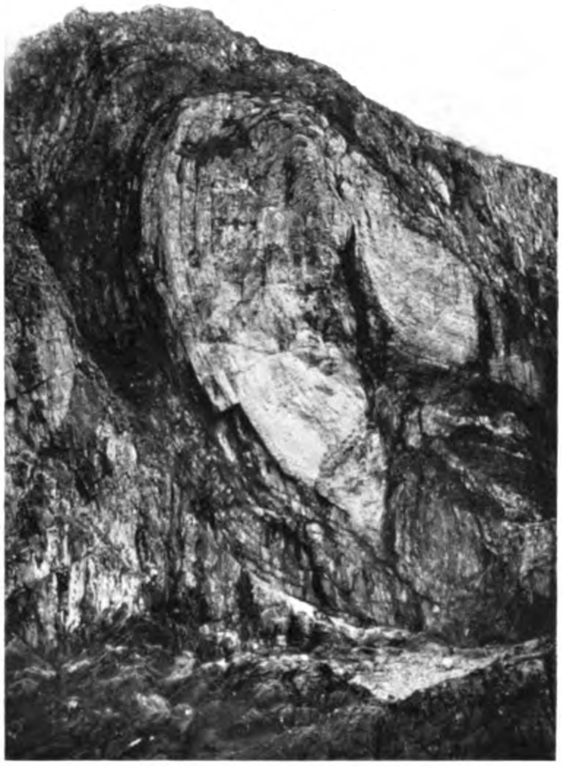
IN this chapter the sequence developed in the description of Islay (pp. 207, 211) is carried through the archipelago to the north.

	GARVELLACHS OR ISLES OF THE SEA	JURA, SCARBA, EILEAN MÒR, LUNGA
? Cambrian		*h*, Q_4. Pebbly Quartzite and Boulder Bed (Pl. XVI, 2) at base with locally derived boulders from underlying group (*g*)—some granite boulders near Kinuachdrach, Jura.
? Cambrian		*g*. Port Ellen Phyllites, east coast of Jura, Scarba, and Lunga—grey and black slates and phyllites with some gritty bands and thin limestones.
? Cambrian		*f*, Q_3. Rudh' a' Mhàil or Jura Quartzite.
? Cambrian		? *e*. Sandy shale and flags with matted worm-casts, so-called fucoids. West coast of Jura and Scarba.
? Cambrian		? *d*, Q_2. Quartzite with 'trumpet pipes' seen at Glengarrisdale, Jura.
? Cambrian	? *c*. Sandy shales with worm-casts, *Planolites*.	
? Cambrian	*b*, Q_1. Flaggy Quartzite with occasional boulders of nordmarkite, &c.	
? Cambrian	*a*. Boulder Beds with nordmarkite boulders and sandy dolomite intercalations (Pl. XVII, 2). Boulders and enormous masses of limestone towards base derived from underlying group (8).	
? Torridonian	(*Strong local Erosion*)	
? Torridonian	8 & 7. Islay Limestone-Phyllite Group.	

The same numbers and letters are used as in the tables on pp. 207, 211.

[1] See Appendix, p. 225.

PLATE XVII



1. Anticline of Islay Limestone flanked by Port Askaig Conglomerate in 200-ft. cliff, Eileach an Naoimh (Garvellachs).

2. Nordmarkite and other boulders in Port Askaig Conglomerate or Boulder-bed, Garbh Eileach (Garvellachs).

It is only in the core of the arch in Eileach an Naoimh of the Garvellachs (Pl. XVII, 1) that any part of the Islay Limestone-Phyllite group has been observed. Just as in Islay there is evidence of local erosion of the limestone and grey phyllites, while the basement breccias (*a*) of the succeeding quartzite series are mostly made up of limestone blocks and debris of sandy and pelitic rocks. Another feature connecting with the phenomena shown in Islay is that intercalations of sandy dolomite alternate with some of these breccia beds. Chiefly above the horizon of dolomitic bands, well-rounded blocks of granitoid rocks make their appearance.

Quartzites occur on Garbh Eileach, the main island of the Garvellach group, and are of the same flaggy character as those of Islay (*b*, Q_1), and they become highly conglomeratic with well-rounded nordmarkite and other foreign boulders. They are not differentiated on Fig. 25. Towards the south-east corner of Garbh Eileach there are some flaggy, sandy and pelitic sediments that may possibly represent one of the zones of so-called 'Fucoid Beds' (*c* or *e*), though no worm-casts were observed in them.

The lowest beds on Scarba are on Sgeir nan Gabhar (Goat's Skerry), forming the north-west angle of the island, where large slabs of sandy flags expose a surface matted with intertwining casts of so-called fucoids. They probably represent part of the 'Upper Fucoid' zone (*e*) of Islay.

The 'Fucoid' Zones or Zone is probably represented on the west coast of north Jura in Bagh Uamh Mhòr (Bay of the Great Cave), near Glengarrisdale (Valley of the Garrison), where 'trumpet pipes' have been observed in quartzite (*?d*, Q_2).

The main quartzite belt through Eilean Dubh Mòr, Lunga, Scarba and Jura certainly belongs to the Rudh' a' Mhàil Quartzite of Islay (*f*, Q_3).

It must now be pointed out that, owing to Bailey's[1] work, coupled with what has already been stated, the order of succession as set forth in the Geological Survey Memoir[2] can no longer be maintained. The chief mistake made is the confounding of the Pebbly Quartzite or 'Boulder Bed' of Scarba and Lunga (*h*, Q_4) with the Port Askaig Conglomerate and the 'Boulder Bed' of the Garvellachs (*a*). I now consider that the two are separated from each other by all the groups (*b*–*g*), including the Rudh' a' Mhàil Quartzite and Port Ellen Phyllites. It is easy to see how the mistake arose. There is a strike fault men-

[1] E. B. Bailey, 'The Islay Anticline (Inner Hebrides)', *Quart. Jour. Geol. Soc.*, vol. lxxii (1917 for 1916), p. 132.

[2] B. N. Peach in 'The Geology of the Seaboard of Mid Argyll', *Mem. Geol. Surv.* (1909), chaps. iii, iv.

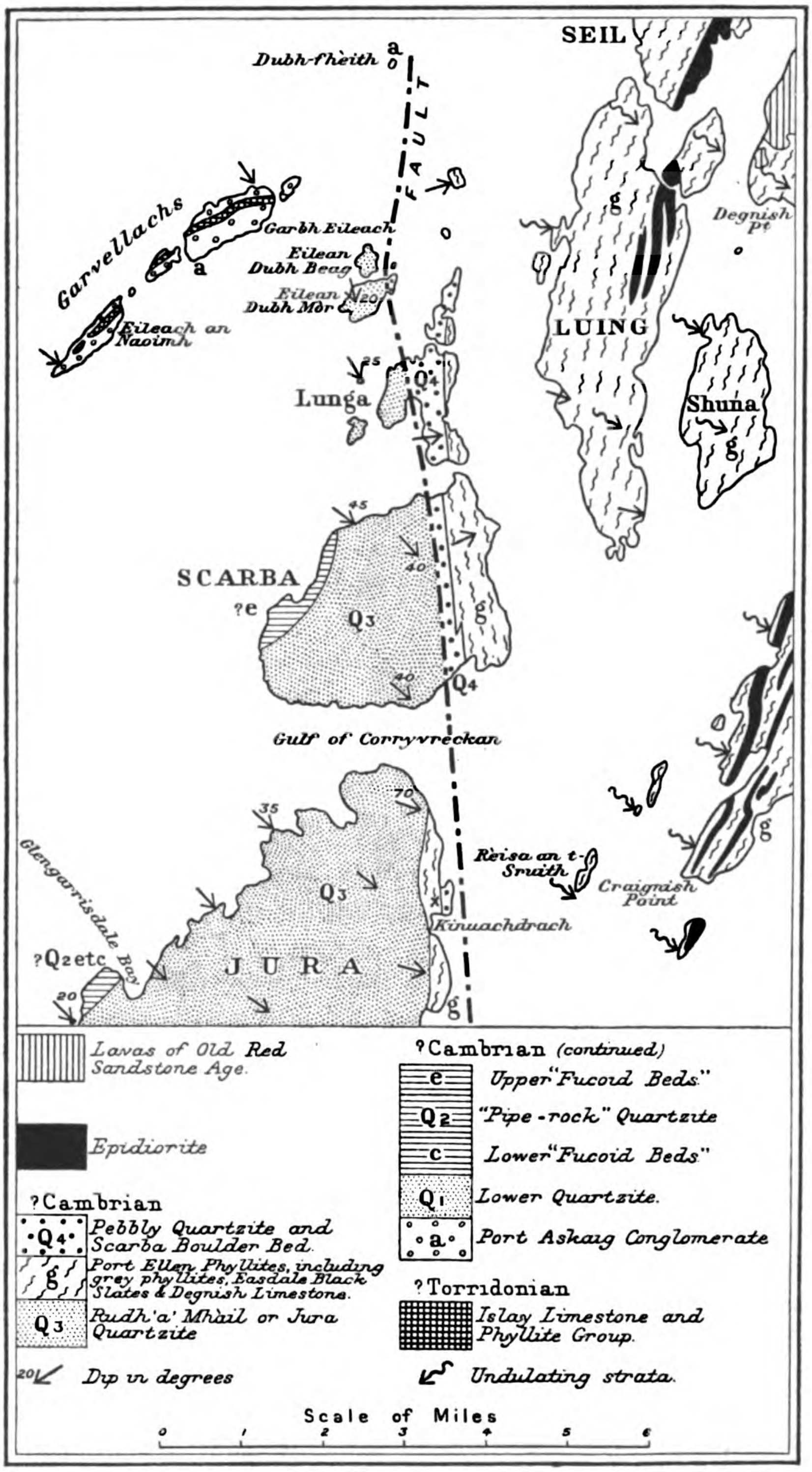


FIG. 25. Map of Northern Jura, Scarba, Luing, and Garvellachs. (*Based on Sheet* 36, *Geol. Surv. One-inch Map Scot.*)

tioned on p. 92 of the Geological Survey Memoir. It traverses Eilean Dubh Mòr, Lunga, Scarba, and perhaps part of Jura, and has a downthrow to the east and not to the west as previously stated. Consequently over the greater part of its course it throws the Pebbly Quartzite or Scarba Boulder Bed (h, Q_4) against successive beds of the Jura or Rudh' a' Mhàil Quartzite (f, Q_3). Fortunately, however, the slates of the intervening group (g) are seen at intervals along the line of the fault in Scarba in a stream gorge near Rudha Righinn which opens on the north shore of Corryvreckan. The same slates

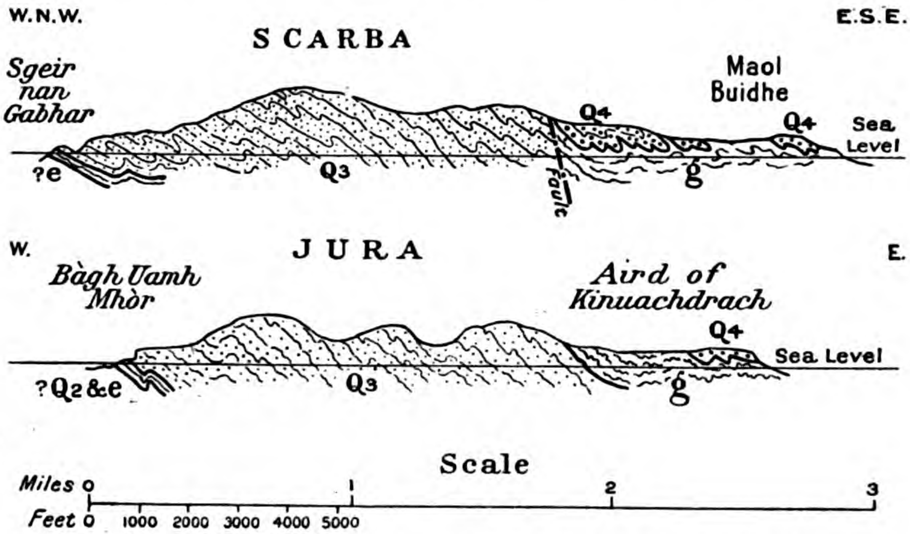


FIG. 26. Sections across Scarba and Northern Jura. For explanation see Fig. 25.

spread out into a wide belt in the Kinuachdrach plain on North Jura, where again they separate the quartzites Q_3 and Q_4. It follows from this *volte-face* that the order of succession of the zones made out in the Rudh' a' Mhàil quartzites (Q_3) as developed in Scarba and the north of Jura has in the past been read in inverse order. The true upward succession is from west to east, so that the sandy calcareous shale and flags with worm-casts (so-called fucoids) exposed on Sgeir nan Gabhar, and at intervals along the west side of the north of Jura, may represent part of group (e) of the 'Upper Fucoid Beds'. The occurrence of 'trumpet pipes' and of a boulder-bed with nordmarkite boulders set in a quartzite matrix near Glengarrisdale on the west coast of Jura helps to strengthen this correlation, since as already indicated it points to the presence of zone (d, Q_2) and even (b, Q_1).

From the above it becomes almost certain that the boulder-beds of the Garvellachs form the true base (a) of the Eilean Mòr, Lunga, and Scarba quartzite series. The limestone in the core of the great fold (Pl. XVII, 1) must represent the Islay Limestone and Phyllite group (p. 207). The evidence obtained from the Garvellachs is strongly in favour of the bottom beds of (*a*), in which great angular masses of limestone (often over eight feet long) occur, being a tillite. The mode of occurrence of the large rounded boulders of nordmarkite (Pl. XVII, 2) which appear higher in the sequence, suggests their having been lifted from some exposed beach and transported hither by floating ice rather than by river action, for the boulders are often found widely separated embedded in a clean sandy matrix.

According to my view the Craignish Phyllites of the mainland are an extension of the Port Ellen Phyllites (*g*), and form the basement member of this group of pelitic and calcareous sediments. The only place where the relation of the Port Ellen Phyllites to the Rudh' a' Mhàil quartzite (*f*, Q_3) is made evident is in the south-west corner of Islay, near Allt an Daimh, two miles east of the Mull of Oa (Fig. 24). There, grey phyllites succeed the quartzite (Q_3) and are interleaved with its uppermost members.

The dark slates and limestones, often referred to as constituting the Easdale Slates, are evidently the upper members of group (*g*), and with their thin limestone bands and occasional quartzite seams form the east side of Scarba and Lunga (Fig. 25). They cover the greater part of Luing, Easdale and Seil, though the grey phyllites are constantly folded up amongst them from below. The dark slates are almost everywhere accompanied by dark fine-grained limestones. The number of these bands cannot be ascertained owing to constant repetition by isoclinal folding which also reduplicates the slates after the manner described by Maufe.[1] The limestones seem to reach a maximum development in the Degnish-Shuna syncline which can be traced as far to the south as Reisa an t-Sruith in the Sound of Jura. The Degnish Limestone must arch over Craignish and reappear, for it is seen at intervals up the Barbeck River and in Eilean Righ and Eilean Macaskin in Loch Craignish.

The following description may be quoted with regard to the Scarba 'Boulder Bed' (*h*, Q_4):

'The striking feature of the deposit is the large size of the included blocks. These conglomeratic beds merely form part of a series containing numerous intercalations of pebbly quartzite. Attention has already been drawn to the fact that the Easdale slates, as developed in Scarba, contain numerous interbedded bands of pebbly quartzite of similar type to that occurring with the boulder-bed, and although the former are abundantly represented in the boulders of the conglomerate, their presence suggests that the line

[1] Plate II of 'The Geology of the Seaboard of Mid Argyll', *Mem. Geol. Surv.* (1909), gives some idea of the intensity of the overfolding in this district.

of erosion, marked though it be in character, may not represent a break of prime importance in the stratigraphy.'[1]

It may not be out of place to recall some facts concerning other boulder-beds in the South-West Highland succession. The frequent recurrence of such boulder-beds showing 'contemporaneous denudation' and often marked by the presence of peculiar granitoid and felsitic boulders (see footnote, p. 212) evidently points to deposition on an area which was undergoing oscillatory crust-movement. The fine sediments of the succession consist of argillaceous material or limestone and indicate periods of local depression; the boulder-beds, on the other hand, show that over the same region compression intermittently caused the sea bed in places to rise to the level of denudation. In fact the phenomena are in all respects comparable with those of Llandeilo and Bala times in the Southern Uplands. The coarse sediments of Islay, Jura, and Scarba appear to have been constantly derived from a region of granitoid rocks in which alkali granites played a conspicuous part, for the pebbly quartzites are made up greatly of blue quartz and microcline felspar grains and the foreign boulders consist mainly of nordmarkite, alkali granites and felsites. In the case of the Scarba Boulder Bed (*h*, Q_4) the fold or folds which brought the sediments now represented by the Easdale Slate of group (*g*) into the zone of denudation must have been of considerable amplitude and must have extended over a wide area. The Scarba Boulder Bed obviously derived its material from a group of strata, comprising calcareous grits and flags, black and grey slates and blue limestones, already well compacted and even jointed. The character of the gritty matrix of the boulder-bed precludes the possibility of its being a 'crush-conglomerate'.

On the mainland the Ardnoe or Crinan Group of pebbly quartzite and limestones (correlated with *h*, Q_4) is seen to be at the base of the Tayvallich volcanic group of the Keills peninsula. Accordingly the movements that give rise to the pebbly grits with the boulder-bed of Scarba were the immediate precursors of that volcanic episode. At the same time the great size of some of the blocks in the Scarba Boulder Bed suggests co-operation of ice.

[1] B. N. Peach in 'The Geology of the Seaboard of Mid Argyll', *Mem. Geol. Surv.* (1909), p. 29.

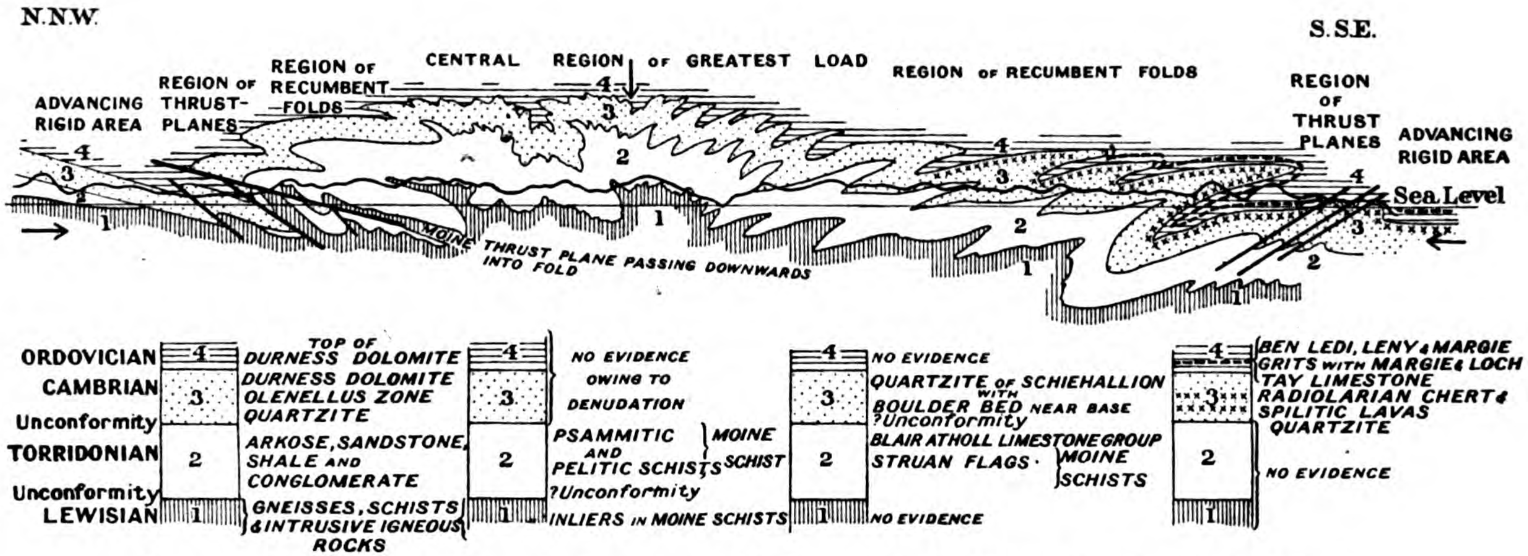


FIG. 27. Diagrammatic section across the entire Highlands drawn by B. N. Peach (see Appendix by Editors).

APPENDIX BY EDITORS

CHAPTERS VI and VII have been reproduced from originals supplied by Dr. Peach to Dr. Horne as a basis for co-operation. It is well known that Dr. Horne disagreed with some of the major conclusions advocated by his colleague, but unfortunately he has left behind him no comment on the manuscript of these two chapters. As the latter were written with the prospect of reconsideration, the editors have felt at liberty to make a few verbal alterations and other minor adjustments, where such seemed desirable from the point of view of clearness of expression. This has been done with scrupulous care, and in the chapters as they stand Dr. Peach tells his own tale in what are essentially his own words.

Dr. Peach also furnished Dr. Horne with notes and horizontal sections for succeeding chapters, but in the main they are too fragmentary for reproduction. Fig. 27 and Pl. XVIII, 1 are here selected as completing in outline Dr. Peach's Highland interpretations. It will be seen that he regarded the Highlands as a folded complex of Lewisian, Torridonian, Cambrian, Ordovician, and Silurian rocks. The long coloured section from the Firth of Lorne to the Firth of Clyde is particularly informative. Dr. Peach has pointed out in the two preceding chapters that he interprets the Q_4 outcrops of Lunga and the other islands of the Islay archipelago as synclinal, and also that he correlates these Q_4 outcrops with the quartzite of Ardnoe, or Crinan, as it is more commonly called, in the Loch Awe syncline. These two relationships are illustrated in the coloured plate. Their significance will be appreciated in the light of the following note written by Dr. Peach:

'Bailey is of opinion that the Craignish Phyllites and Ardnoe or Crinan Beds form a different nappe from the Islay-Jura-Scarba-Lunga rocks, and that the two nappes are separated from one another by a "slide" which conveniently hides itself under the sea. Whether this be the case or not, it is quite evident that the conditions of deposit of the two sets of rocks must have been almost identical and they are evidently parts of one and the same series.'

Other points in the section to which special attention may be directed are:

(1) the correlation of the Errins or Loch Fyne Quartzite with Q_4;

(2) the correlation of the Tayvallich or Keills pillow lavas with the Highland Border pillow lavas;

(3) the correlation of the Loch Tay Limestone with the Margie Limestone of the Highland Border;

(4) the underground connexions that have been drawn beneath the Cowal Anticline of Foliation at Glen Tarsann.

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